

The University of Texas at Austin

Department of Astronomy

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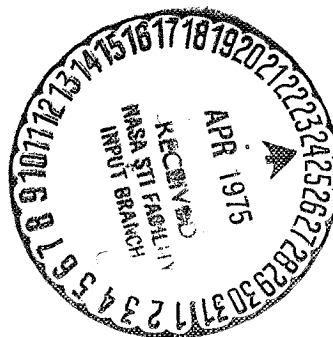
SEMIANNUAL REPORT #3

Period September 1, 1974-February 28, 1975

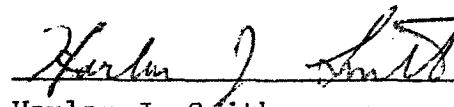
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Harlan J. Smith

I. Personnel working on this grant during this reporting period:

Dr. Harlan J. Smith (Principal Investigator, not charged to grant)
Dr. Laurence M. Trafton (Co-Investigator, full-time on grant)
Dr. Edwin S. Barker (Co-Investigator, full-time on grant)
Robert G. Tull (Research Associate, 45% time on grant)
Dr. William W. Macy (Post doctoral fellow, full-time on grant)
Mr. Michael A. Perry (Research Assistant, full-time on grant)
Mr. Jerry Woodman (Graduate student, half-time)
Miss Winifred Williams (Graduate student, half-time)
Dr. Michelle Kaufman (Computer and data reduction support in Austin half-time)
Mr. Carl Michelis (Computer and data reduction support in Austin half-time)
Mrs. Amber Woodman (Computer and data reduction support at McDonald Observatory, hourly, half-time)

Personnel Changes:

Effective March 12, 1975, Edwin S. Barker went on leave without pay from the University of Texas at Austin to accept a two-year visiting astronomer position with Princeton University Observatory. He will be developing a new fast-data mode for the OAO-C (Copernicus) ultra-violet spectrometer. Upon completion of this fast data mode, which will lower the background noise by a factor of 100X and open the 2-3000A region to fainter objects, he will devote at least half time to high dispersion observations of ultra-violet solar system objects (Mars, Jupiter, Saturn, Io, Titan). During the two-year period he plans to remain in close touch with the NASA-Texas observing program at McDonald, directing the Mars H₂O and Venus H₂O-CO₂ monitor programs and other observations planned under the current grant period. One such program is the cooperative Venus Week observing run planned for the first two weeks of May, for which he plans to return to McDonald.

We intend to hire a post-doctoral astronomer to perform the work Barker was doing at the Observatory. Mike Perry is currently making the observations of Mars and Venus for this grant under Barker's direction.

II. Overview and Summary

Observational Programs: During four 107-inch observing runs emphasis was placed on: Venus CO₂ line strengths and CO₂ line profiles at small phase angles; start of Mars H₂O studies for 1976 apparition; the spatial distribution of Io's sodium cloud; Titan's λ 8272 feature; and the Raman effect in Jupiter and Saturn.

Instrumentation: The Tull-coude scanner and the 107-inch telescope performed well. The detector pedestal was modified to mount the Tull Self-Scanned-Digicon (a multichannel detector) at the coude scanner focus to be used in the grating or echelle mode and allow a quick changeover to the normal scanner system. Initial tests show that this instrument is shot-noise limited.

Data Reduction and Analysis: All the 1972-74 H₂O measurements on Venus and Mars were converted into abundances. A correlation program was developed to compare simultaneous H₂O and CO₂ measurements on Venus and Martian H₂O abundances with Martian elevations. The CO₂ line profile data on Venus was processed to final form and compared to an isotropic, homogeneous atmosphere for Venus. The spatial observations of Io's sodium emission were reduced and analyzed. They were presented at the DPS meeting and at the Io week workshop held at Harvard on 22 February. The Raman data is in the first stages of reduction. Further reduction of the H₂ quadrupole and pressure-induced spectra has been postponed to after the DPS meeting.

Other work is summarized in the titles of our publications and papers listed in Section IX.

External Communications: We gave five papers at the 6th Annual Division of Planetary Sciences meeting in February, two papers at the GISS Conference on the Atmosphere of Venus in October, one paper to the Viking Lander Group meeting in November, one paper to the Io Week Conference in February, and one paper at the Uranus Workshop at NASA Ames in October.

Foreign Travel: None during period.

III. Observational Research Program

Observing Runs (NASA-Texas--107-inch)

Scheduled Runs	Dates	Telescope Hours		
		Possible ¹	Unobservable ²	Observed ³
1	1 Sept-10 Sept, 1974	200	53	125
2	6 Nov-10 Nov, 1974	110	90	20
3	28 Nov-8 Dec, 1974	242	121	88
4	3 Jan-8 Jan, 1975	132	24	80
Unscheduled Runs				
	October (Venus)	-	-	5.5
	November (Venus)	-	-	16.0
	November (Mars)	-	-	4.0
	January (Solar)	-	-	26.0

¹Possible hours = hours during which planets of interest were available minus time of laser runs (2 hours per day)

²Unobservable hours = bad weather hours (seeing, clouds, humidity, dust, etc, plus any instrumental down time)

³Observed hours = hours of actual planet observation or calibration

Comments on Observing Runs

During Run 1, the humidity was low enough to permit observations of Venus H₂O lines with only 0.10 to 0.15Å Doppler shift on several days. Observations were made at phase angles of 20° to 5° on Venus during the unscheduled runs when the 107-inch telescope was not being used at coude in daytime by stellar observers. These observations close to the sun (especially those <10°) required exceptional transparency, lack of haze and good seeing. The fact that we were able to obtain some 70 hours of good CO₂ line profile and line strength data proves the importance of being able to use non-scheduled daytime observing. No special problems were presented during the evening runs except that bad weather prevented the completion of some observing programs.

Observing Runs - (Non-Texas Users)

<u>Telescope</u>	<u>Dates</u>	<u>Observers Affiliations</u>
107-inch	4-10 October, 1974	Potter - MSC
107-inch	21-27 October, 1974	Beer - JPL
107-inch	22-27 November, 1974	Owen - SUNY - Woodman
107-inch	20-26 January, 1975	Beer - JPL
82-inch	28-29 October, 1975	L. Young - Texas A & M

Venus

Venus CO₂ Line Profiles

Our primary Venus goal during this reporting period was to obtain data on two CO₂ lines (P16, 8689Å band and P14, 7820Å band) at small phase angles. The successful completion of this project was due to utilization of the unscheduled daytime observing during October and November, which allowed us to pick the best days for observations. A total of 36 line profiles were obtained between phase angles of 24° and 5°.

Venus--H₂O and CO₂ Variability

The current phase of this program was completed by observations in September at phase angles of 25° to 20° and the submission of three papers for publication. These papers and abstracts are appended to this report.

Venus--CO₂ Line Strengths

We obtained good small phase angle coverage using the P branch of the 8689Å CO₂ band. Twenty-five scans were obtained over a phase angle range of 20° to 6°.

Mars

Mars--H₂O Studies

Work was begun on the 1974-76 apparition during late November when Mars was only 3.8 arcsec in diameter. Observations will continue into the fall of 1975, covering an L_S range of 140° to 290° .

Jupiter

During the Pioneer 11 flyby of Jupiter, Trafton obtained spectra of Jupiter's H₂ quadrupole lines in order to monitor Jupiter's atmospheric state at this time. This will support the Pioneer experiments by providing information on the normalcy of Jupiter's atmosphere at the time of the flyby. Results from the radio occultation experiment suggesting a hot ($\sim 500^\circ\text{K}$) upper atmosphere remain in contradiction with these results indicating that some other interpretation of the occultation experiment is required. Other earth-based observations are also in conflict with a hot upper atmosphere for Jupiter but they were obtained at other times. Our measurements show that Jupiter was not abnormal at the time of the measurement.

A number of H₂ quadrupole lines of the (3-0) band were recently scanned at various positions on Jupiter's disk for spatial studies (12 observations).

Spectra for study of the Raman effect in Jupiter's atmosphere have been obtained at intermediate and higher resolution from $\lambda 3000$ to $\lambda 4400$ (13 spectra) by Trafton and Woodman. They also obtained corresponding Lunar and Solar comparison spectra. These data are currently being reduced and analyzed.

Observations of the $3\nu_3$ CH₄ band's R(1), R(2) and R(7) manifold and Q branch were obtained for further study (9 spectra). The R(7) manifold was obtained in belts and zones and on the Red Spot for spatial studies.

Three lines of NH₃ were obtained at high resolution ($0.05\text{\AA}$) for study of the effective pressure. These are singlets identified by Giver and so should be free of this ambiguity present in earlier studies.

Saturn

Ultraviolet scans from $\lambda 3000$ to $\lambda 4400$ were obtained for later study of the Raman effect in Saturn's atmosphere.

Uranus

No observations were made during this period.

Neptune

No observations were made during this period (except for Triton comparisons).

Io

During this period, L. Trafton studied the spatial distribution of Io's Na cloud, taking 67 medium resolution spectra ($1.5\text{\AA}$) of both the D_2 and D_1 lines simultaneously, 6 higher resolution ($0.15\text{\AA}$) spectra of these lines individually, and 5 high resolution spectra ($0.05\text{\AA}$) of D_2 for line profile studies. For this purpose, a number of comparison spectra were also obtained of the Moon, JIII and Jupiter. He found the emission intensity distribution to be asymmetric with respect to the orbital plane and suggestive of asymmetric radial streaming of Na from Io. He also found a correlation between the side of Io's orbital plane having the greatest emission intensity and Io's magnetic latitude. This suggests that particles in the magnetic equator may deplete the sodium escaping from Io. These results were presented by L. Trafton in a paper by himself and W. Macy at the Columbia DPS meeting.

Trafton also attempted to detect He in Io's cloud after the announcement of its discovery was made at the IAU Colloquium #28. He detected He in each of several observations but found no enhancement near Io. He concluded from this and its low strength (0.1 to 1 KR) that it originated from the night sky and not from Io. He communicated this to those who made the announcement at the IAU colloquium. They later retracted their claim of He in Io's cloud, pointing to the He-Ne laser in their interferometer as the source of the He emission line in their data. (They had been considering this possibility at the time Trafton communicated his results to them.)

Finally, Trafton scanned Io's cloud throughout the visible-near infrared spectrum in search of other emission lines than Na. These data are currently being reduced but no obvious emissions are apparent.

Titan

Six scans of the $S_3(0)$ H_2 region were obtained along with Saturn and Lunar comparisons. These help to fill a void in the study of the possible H_2 features. As with the $\lambda 8150$ region, weak absorptions continue to be evident.

High photometric-accuracy scans of Titan in the spectral region $\lambda 4500$ to $\lambda 6300$ (5 spectra) were obtained to extend the study of Titan's bands to blue wavelengths. Comparison scans of Saturn were also obtained.

Six observations of a feature at $\lambda 6450$ were obtained along with Jupiter, Saturn and Lunar comparisons in an attempt to identify this new feature and resolve it into lines. It coincides with the $\lambda 6420$ feature in Uranus' and Neptune's atmospheres attributed either to pressure induced H_2 or to CH_4 . This feature is stronger in Titan's spectrum than in the spectrum of Saturn and it remains unidentified.

Triton

Six observations from $\lambda 3100$ to $\lambda 5000$ were obtained with 10 Neptune comparisons to study the behavior of the UV spectral albedo of Triton. These are being reduced in an attempt to detect an atmosphere through Rayleigh scattering. A significant atmosphere would cause an upturn in the UV reflectivity with decreasing wavelength.

IV. Future Observing Runs

Prime objects and programs on the 107-inch

17 March - 23 March	<u>Venus</u> - CO ₂ line profiles
31 March - 4 April	<u>Mars</u> - H ₂ O L _s coverage
	<u>Titan and Saturn</u> H ₂ Monitor
	<u>Uranus</u> - HD and H ₂ Monitor
11 April - 17 April	<u>Venus</u> - Joint project with Potter of MSC to measure HF and H ₂ O at same points on disk
18 April - 24 April	<u>Venus</u> - continue above program
	<u>Mars</u> - H ₂ O - L _s coverage
	<u>Saturn</u> - Complete H ₂ Monitor, CH ₄ bands
	<u>Uranus</u> - Raman effect, Period, HD
	<u>Neptune</u> - H ₂
1 May - 14 May	<u>Venus</u> - many observational programs coordinated by GISS and JPL
	- H ₂ O distribution
	- 30-inch UV cloud contrasts
29 May - 5 June	<u>Venus</u> - CO ₂ line profiles
	- UV albedo
	<u>Mars</u> - H ₂ O - L _s and spatial coverage
	<u>Neptune and Triton</u> - CH ₄ bands, H ₂
July, August	<u>Jupiter, Io's sodium cloud</u>

V. Instrumentation Development

The Self-Scanned Digicon developed by R. G. Tull was installed in the coude spectrograph of the 107-inch telescope in December, along with the hardware operating system developed by Tull and Mr. Steven Vogt, and the software system "Bugeye II" developed by Mr. Phillip Kelton. Observations were carried out in December, 1974, and in February, 1975, during two scheduled observing runs by Tull, Vogt, Dr. David L. Lambert and Dr. J. Tomkin, primarily on stellar high dispersion spectra to evaluate the performance. On BY Draconis (B = 9.2), an M dwarf flare star, a high-quality spectrum was obtained in 2 1/2 hours at 1 Å/mm, resolution 0.15 Å, to a signal/noise ratio of 30 over a 25 Å region near 4300 Å. The noise performance has been demonstrated to be photoelectron shot noise limited; we consider the performance during these test observations to have been quite good, but by no means optimum. Additional work is planned in June, 1975, to make the following changes:

- 1) Change camera focal ratio from f/33 to f/9 to change the image scale on the photocathode.
- 2) Install a J-Y holographic grating monochromator as an order sorter for use with the echelle. This will replace the cross dispersing grating.
- 3) Re-align the echelle for single-pass operation. (This is made possible by the monochromators.)

The result of these changes is expected to be improved optical coupling between spectrograph and self-scanned digicon, improved efficiency, and decreased set-up time. The decreased angular dispersion at the photocathode will in part be offset by increased linear resolution at the resulting smaller image scale.

A paper is in press in Applied Optics to appear in May, 1975.

The photomultiplier mounts for the coude scanner were re-built during this period to improve stability and reduce set-up time. Each photomultiplier cold box is now mounted kinematically on the scanner pedestal, and is adjusted independently of the remaining photomultipliers. Interchanges of cold boxes are now made simply and quickly and without need for re-adjustment.

VI. Data Reduction

Data reduction for the Tull-coude scanner takes place in two stages: 1) card copy and plotting, usually done within 24 hours by Mrs. Woodman at McDonald Observatory and 2) refined smoothing, sky removal, ratio spectra, and measurement. These are usually performed by Mrs. Woodman and Mr. Perry at McDonald Observatory and by Mr. Michelis and Mr. Day in Austin.

Venus - Line Profiles

The CO₂ line profile data are now in final form with the solar spectrum removed. Any residual vignetting and equivalent widths have been measured for the P16 line of the 8689A band. We have a sufficient data set of CO₂ line profiles now to test models of the Venus atmospheric structure. A preliminary test using an isotropic homogeneous atmosphere indicates that an inhomogeneous atmosphere is required and cloud layers would explain the overall shape of the line profile. Further analysis with more complicated modeling will be attempted during the remainder of this grant period. A preliminary report on this comparison was given in a DPS paper.

Venus - CO₂ Line Strengths

All data obtained to date have been reduced and a paper was prepared and accepted for publication on the semi-periodic variation of the CO₂ abundance. The recently obtained line strength data at small phase angles show the "cloud bow" effect at 15-20° phase angle as predicted by Whitehill and Hansen for an inhomogeneous, anisotropic scattering atmosphere with a sulfuric acid phase function. The measured equivalent widths of the line profile data also show a similar effect.

Venus - H₂O and CO₂ Observations

Data reductions are completed and two papers submitted and accepted. A comparison with UV markings will be made with this large amount of H₂O and CO₂ data and near simultaneous UV photographs taken by the International Planetary Patrol, McDonald and New Mexico State University.

Venus - Albedo

Data reductions were completed and a joint observational paper with Dr. Hapke and Mr. Nelson of the University of Pittsburgh was written and accepted for publication. Dr. Hapke's laboratory measurements results in an identification of the UV absorber as a polymorphic form of elemental sulfur. Our data rule out dihydrated Ferrous Chloride as a cloud constituent.

Mars

Mars - H₂O

Data reduction has been completed on the 1972-74 data (469 individual observations) with a complete paper now in final form for submission to Icarus. Results are described in Semi-annual Report #2 and were presented to the Viking Landing Site review meeting in November, 1974. A correlation analysis of the H₂O abundance and mean elevation with respect to the 6.1mb surface shows no correlation, except that possibly during the wetter seasons more H₂O vapor is present over lower regions.

Outer Planets and Satellites

Since these objects are much dimmer, scanning time is considerably longer so that reduction of the observations is not the problem it is for the inner planets. The data are routinely smoothed, plotted and ratioed to eliminate telluric absorption or vignetting after every observing run. This includes subtraction of dark or sky background and summation to increase the signal to noise ratio. Later, continuum levels are drawn and equivalent widths measured for analysis.

VII. Analysis and Theoretical Studies

Analysis of the Uranus H₂ observations has progressed to the point of arriving at a model of Uranus' atmosphere which explains both the quadrupole and pressure-induced spectra. This was accomplished by using an inhomogeneous planetary atmosphere program written by P. Wannier following the doubling prescription of J. Hansen. We earlier modified this program to allow for pressure shifts of the quadrupole lines and updated constants relating to pressure broadening and narrowing of these lines. Final computations still remain to be done in the second half of the grant period. Following Uranus and Neptune, hydrogen on Jupiter and Saturn will be analyzed.

We have continued a heavy investment in time and effort into the problem of Io's sodium cloud. Analyzing the spatial extent of this emission, we find traces several minutes of arc from Io. The intensity falls off as $1/r$ from Io suggesting a streaming model where Io is the source. Resonant scattering still appears to be the dominant emission mechanism. The torus part of the cloud is weaker than the streaming part, some of which escapes into space. We have discovered asymmetrical shapes in the line profiles. Streaming velocities of 7-15 km/s are indicated from the November and December data. Finally, we have found a correlation with the magnetic latitude of Io and the directionality of the sodium emission. These results we presented at the DPS meeting and at the Io-Week workshop.

Following the recent surge of interest in Uranus and Neptune, we extended the analysis of Murphy and Trafton (1974) to include models having temperature inversions. This was required by recent observations made by Reike and Low (Ap.J. Letters 193, 147) and, in the case of Uranus, their interpretation in terms of an inversion by L. Wallace (Uranus Workshop). We still find that Neptune must have a significant internal heat source in order to support this inversion and explain the infrared

brightness temperatures. That is, the inversion alone cannot explain the observed brightness temperatures. We presented this research at the 1975 DPS meeting.

J. Woodman continued the reduction and analysis of his data on the spatial variation of molecular absorption bands on Jupiter. When the observations are interpreted in terms of a two-cloud-layer model for the vertical structure of the Jovian atmosphere, insight is obtained into the structural differences of various regions of the planet. He is also continuing the analysis of laboratory spectra of methane obtained at JPL to aid in the interpretation of the Jupiter data.

VIII. Laboratory Investigations

None have been carried out during this reporting period.

IX. Publications and Presentations during this reporting period

A) Published Papers:

- 1) "The Abundance of Ammonia on Jupiter, Saturn and Titan", T. Encrenaz, T. Owen and J. Woodman, Astron. and Astrophys. 37, 49.
- 2) "On the Abundance of NO₂ in the Martian Atmosphere", T. Owen, T. Scattergood and J. Woodman, Icarus, 24, 193.
- ✓ 3) "Evidence for an Internal Heat Source in Neptune", R. E. Murphy and L. Trafton, Ap. J. 193, 253.
- ✓ 4) "The Source of Neptune's Internal Heat and the Value of Neptune's Tidal Q", L. Trafton, Ap. J. 193, 477.
- ✓ 5) "Jupiter: A Comment on the 8- to 14- μ Limb Darkening", L. Trafton R. Wildey, Ap. J. 194, 499.
- ✓ 6) "The Morphology of Titan's Methane Bands. I. Comparison with a Reflecting Layer Model", L. Trafton, Ap. J. 195, 805

B) Papers Submitted for Publication:

- ✓ 1) "Relative Spectrophotometry of Venus from 3067 to 5960Å," E. S. Barker, J. H. Woodman, M. A. Perry, B. A. Hapke and R. Nelson, J. of Atmos. Sci., June, 1975, Venus Issue.
- ✓ 2) "Comparison of Simultaneous Observations of H₂O and CO₂ on Venus", E. S. Barker, J. of Atmos. Sci., June, 1975. Venus Issue.
- ✓ 3) "Observations of Venus Water Vapor over the Disk of Venus: The 1972-74 Data using the H₂O lines at 8197Å and 8176Å", E. S. Barker, Icarus.
- ✓ 4) "Semi-periodic Variations in CO₂ Abundance on Venus", E. S. Barker, Icarus.
- 5) "Saturn's 3 μ Methane Band: An Analysis in Terms of a Scattering Atmosphere", L. Trafton and W. Macy, Jr. Ap.J.

- 6) "Io's Sodium Emission Cloud", W. Macy, Jr. and L. Trafton, Icarus.
- 7) "Near-Infrared Spectrophotometry of Titan", L. Trafton, Icarus.
- 8) "A Model for Io's Atmosphere and Sodium Cloud", W. Macy and L. Trafton, Ap.J.
- 9) "The Self-Scanned Digicon: A Digital Image Tube for Astronomical Spectroscopy", R. Tull, J. Choisser, and E. Snow, Appl. Opt. 14.
- 10) "Pioneer 11 Infrared Radiometer Experiment: The Global Heat Balance of Jupiter", A. Ingersoll, G. Munch, G. Neugebauer, D. Diner, G. Orton, B. Schupler, M. Schroeder, S. Chase, R. Ruiz, and L. Trafton, Science.

C) Presentations and Abstracts:

- 1) At the Goddard Institute of Space Studies Conference on the Atmosphere of Venus, 11-14 October 1974 by E. S. Barker .
 - a) Relative Spectrophotometry of Venus from 3000 to 6000A.
 - b) CO₂ and H₂O Observations of Venus
- 2) At the Viking Lander Working Group meeting at Langley AFB, VA 3-4 November 1974 by E. S. Barker, Observations of the Mars H₂O Distribution During the 1972-74 Apparition.
- 3) At Harvard University 12 December 1974 by J. H. Woodman, Spatial Studies of CH₄ and NH₃ over the Disk of Jupiter.
- 4) At the Uranus Workshop held at NASA Ames 30 September- 2 October, L. Trafton participated in a study of scientific conditions relevant to an atmospheric probe for Uranus. He presented a critical review of Uranus' spectroscopic data which will be published in a NASA CR.
- 5) At the Io-Week Workshop held at Harvard on 22 February, L. Trafton presented his research on Io's sodium cloud. He was one of the co-sponsors of the meeting.
- 6) At 6th Annual Meeting of the Division of Planetary Sciences of the AAS, 17-21 February 1975 at Columbia, MD
 - a) "Martian Atmospheric Water Vapor Observations 1972-74 Apparition", E. S. Barker, BAAS, 7, 1975.
 - b) "Vertical Structure Studies of the Atmosphere of Venus Using CO₂ Line Profiles", E. S. Barker, W. Macy, Jr. and L.M. Trafton, BAAS, 7, 1975.
 - c) "Comparison of Simultaneous CO₂ Measurements on Venus with Different Telescopes and Techniques", R. A. J. Schorn, E. S. Barker, L. D. G. Young, BAAS, 7, 1975.

- d) "Spatial Variations of Molecular Absorptions on Jupiter", J. H. Woodman, BAAS, 7, 1975.
- e) "Neptune's Atmosphere: Concerning the Thermal Structure", W. Macy, Jr. and L. M. Trafton, BAAS, 7, 1975.
- f) "Geometry of Io's Sodium Cloud", L. M. Trafton and W. Macy, Jr., BAAS, 7, 1975.
- g) "Pioneer II Infrared Radiometer Experiment", A. Ingersoll, G. Munch, G. Neugebauer, D. Diner, G. Orton, B. Schupler, M. Schroeder, S. Chase, R. Ruiz, and L. Trafton, BAAS, 7, 1975.

X. Financial and Travel

No foreign travel was made during this report period and none is planned for the next period. In addition to travel to the Columbia DPS meeting in February (Smith, Trafton, Macy, Barker and Woodman), Barker attended the Venus Conference at NASA Goddard in October and Trafton attended the Uranus Workshop at NASA Ames in October.

Expenditures for the first half of the fiscal year 1974-75 are remaining within budget (expenditures so far committed totaling \$136,000).

Comparison of Simultaneous CO₂ and H₂O
Observations of Venus

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RICHARD A. CRAIG

ABSTRACT

During the 1972-74 period, 115 pairs of CO_2 and H_2O abundance determinations have been made with the coude scanner of the 2.7m reflector at McDonald Observatory. These observations were made on 35 days usually within one to three hours of each other. The pairs of observations were made over the same area of the illuminated disk of Venus with the guiding, seeing and slit placement errors less than 15% of the disk diameter.

A correlation analysis of the pairs of observations grouping them into eight periods of time which corresponded to telescope observing runs or periods of similar phase angle shows a lack of correlation in all except one period. For this set, the H_2O abundances were positively correlated with the relative CO_2 line strengths for measurements of the 8689Å CO_2 and 7820Å CO_2 bands made on the same day. Comparison of abundances on some 25 individual days shows a positive correlation on one day and a marginal negative correlation on two days with no correlation on the remaining 22 days.

On the basis of the lack of correlations, one has to conclude that either the H_2O level of line formation does not fluctuate in phase with the observed CO_2 absorption fluctuations or the horizontal distribution of the H_2O vapor must be inhomogeneous.

1. Introduction

In the past several years at McDonald Observatory the H_2O and CO_2 abundances in Venus' atmosphere have been measured routinely as part of the NASA-Texas Planetary Program. The earlier photographic high dispersion spectrographic results from the 207cm coude spectrograph at McDonald Observatory were the subject of a series of paper on the CO_2 and H_2O abundances during the years 1966 to 1971 (Gray and Schorn, 1968; Gray, *et al.*, 1969; Schorn, *et al.*, 1969a, 1969b, 1970, 1971; Young, *et al.*, 1969, 1970, 1971). With the installation of the echelle grating in the coude scanner of the 272cm reflector, the resolution, speed and photoelectric accuracy improved to the point where it was possible to obtain a high precision scan of an H_2O line or the P branch of a CO_2 band in 10 to 15 minutes instead of one to two hours previously needed. This rapid mode of observation has allowed us to observe several locations on the planet during periods of good seeing (1-2 arcsec) using an H_2O line and several lines of the P branches of either the 7820Å or 8689Å CO_2 bands. With the possibility of measuring the H_2O and CO_2 abundances within a few hours for several positions on the disk of Venus, we have attempted to make such observations during the past two years whenever the Doppler shifts were large enough and the seeing conditions were good and stable. Most of the com-

parisons are between the P branch of the 8689Å CO_2 band and the 8197Å H_2O line since the majority of the CO_2 measurements were made of this band because the band is roughly 10 times stronger than the 7820Å CO_2 band. On 5 days in September of 1972, we obtained observations of both of the CO_2 bands and the 8197Å H_2O line.

The data presented in Table 1 are the matching pairs of CO_2 and H_2O measurements found in the more extensive H_2O and CO_2 observations presented by Barker (1975) and Barker and Perry (1975) hereafter referred to as Paper I and Paper II. Preliminary results were reported by Barker (1974a, b). Paper I presents all of the H_2O total, two-way abundances ($\eta\omega$) obtained during 1972-74 as functions of locations on the illuminated crescent and phase angle. These total, two-way abundances ($\eta\omega$) have been calculated from the equivalent widths presented in Paper I and the assumptions of an effective pressure of 136mb and a temperature of 250°K for a reflecting layer model. The conclusions were: (1) there is no preferential location on the illuminated disk for the water vapor which had values of $1 \leq \eta\omega \leq 77\mu\text{m}$ of precipitable water vapor between $30^\circ < i < 110^\circ$, and (2) only at moderate phase angles, $30^\circ < i < 110^\circ$, does the abundance reach $30\mu\text{m}$ or above, while small but detectable amounts of $1 \leq \eta\omega \leq 10\mu\text{m}$ are present at other observed phase angles, $20^\circ < i < 30^\circ$ and $110^\circ < i < 162^\circ$.

The semi-periodic variations in the CO_2 relative line

strengths for the 8689Å CO_2 band were presented in Paper II. Seven observational runs produced periodic fluctuations of 20 to 50% in the CO_2 line strength and periodicities of four, six and greater than nine days. A four-day periodicity was ruled out in two other short observing runs. The increase in the CO_2 line strength asymmetry with phase angle during 1973 between the northern and southern portions of the illuminated disk was due to the progressive shift of the northern half of the illuminated disk into the equatorial regions of Venus' atmosphere and likewise the shift of the southern half of the illuminated disk into the polar regions of the atmosphere. Near inferior conjunction this asymmetry had increased to a factor of two with the equatorial regions having about 0.5 the central CO_2 line depth of the polar regions. Hence the level of line formation must be higher over the equatorial regions of the atmosphere.

The objective of this paper is to compare the H_2O and CO_2 abundances obtained for the same region of Venus on the same day, hopefully leading to the reason why the H_2O vapor amounts vary so drastically over the disk.

2. Observations and reductions

Table 1 gives the average CO_2 line strength determined from the CO_2 scan and the H_2O abundance measured on a scan of the same portion of the illuminated disk within one to three hours. The slit of the spectrograph was oriented

with respect to the intensity equator of Venus by means of an image rotator which was left running once it has been aligned for the day. The positions of the slit at various fractions of the disk diameter were determined by using a graduated scale (1 division = 0.7 arcsec) in the guiding eyepiece. The repeatability of the slit position was determined by the seeing smearing and the guiding errors which were estimated to be one to two arcsec or less than 15% of the disk diameter.

The CO₂ observations usually preceded the H₂O observations by about 1.5 hours which was a typical time needed to complete five slit positions. The H₂O observations were usually made during meridian transit followed by an additional set of scans of the other CO₂ band. The seeing disk varied from 1 to 3 arcsec for the majority of the observations and non-equatorial slit locations were not attempted if the seeing was worse than about 4 arcsec.

The photoelectric scan reductions were carried out by standard techniques previously described in Papers I and II. The relative CO₂ line strength is the average ratio between the observed central depth of selected CO₂ lines and the observed central depth of a standard normalized solar line within the 8689Å CO₂ band. Since no solar line was available in the 7820Å CO₂ band, the relative CO₂ line strength is just the average observed central depth of selected CO₂ lines in the 7820Å CO₂ band.

The phase angle dependence of the relative CO_2 line strength is the reason the values of $R_{\text{CO}_2}(\theta)$ decreased with time in 1973. We have broken the correlation analysis for the 8689Å CO_2 band into sets of pairs at different phase angles because both the CO_2 and H_2O (Paper I) abundances vary with phase angle.

3. Results and discussion

The criteria of good, stable seeing and both H_2O and CO_2 observations made at the same position on the illuminated disk within one to three hours limited the overall data sets to 115 pairs of abundance measurements on a total of 35 days. The pairs of scans are plotted in Fig. 1, divided into eight sets of data points. Visual inspection agrees with the formal correlation coefficient (r) between pairs of relative CO_2 line strength $R_{\text{CO}_2}(\theta)$ and total two-way abundance measurements given in Table 2. Correlations are not present in the data sets except for the 8689Å CO_2 September 1972 set and the 7820Å CO_2 September 1972 set. When the 7820Å data set is expanded to include the 7 pairs of observations on Julian Day (JD) = 2441555. (25 August 1972), the correlation coefficient confidence level is reduced from 99% to 90%. Consequently, one single day's set of observations, JD = 2441555., had nullified the positive correlation existing on the other four days.

Because of the effect of a single day on the correla-

tion coefficient of the 7820Å CO₂ September 1972 data set, the correlation coefficients were calculated for each individual day having three or more pairs of abundances. These daily correlation coefficients are presented in Table 3 for 25 days. Out of the 25 days when three or more pairs existed, on only two days marginal negative correlation coefficients were found having a 90% confidence level that the indicated correlation was real and was not due to a random number correlation. Only a single day (29 September 1972) had a positive and believable correlation (95% level). No single day in the September 1972 data set had a valid correlation.

The lack of any correlation during the time period near inferior conjunction ($130^\circ < i < 162^\circ$) is present in the 1974 pre- and post-inferior conjunction data, although there were the large variations (up to 100%) in the relative CO₂ line strengths and H₂O abundances. For example, the relative CO₂ line strengths at the CC S22 (center of illuminated crescent 22° south from the intensity equator) location were 15 to 30% stronger than those in the CC N22 locations (Paper I) and the H₂O abundances were also quite variable from 1 to 10μm. The quality of the H₂O observations (errors of ±5 to 10μm) is not as high as the other H₂O data primarily because of the very small Doppler shifts of about 0.1Å at large phase angles.

The lack of some type of correlation between the CO₂ and H₂O abundances was unexpected because of the large semi-

periodic variations in the planet-wide CO_2 with a period of a few days and particularly because the relative CO_2 line strengths at all slit positions follow in phase with each other (Paper II). Since no significant abundance correlations have been observed except for the September 1972 data set for which no single day had a valid correlation and the planet-wide CO_2 abundance is known to fluctuate (Young, *et al.*, 1973, 1974 and Paper II), the horizontal or planet-wide distribution of H_2O vapor must be inhomogeneous. H_2O is a minor constituent (10^{-6}) in the atmosphere of Venus and could easily be inhomogeneously distributed over the planet. Although it might have on the average over several days and years a uniform distribution over the disk of Venus (Paper II); for observations on a single day, a very patchy distribution is the usual observed case with factors of five in H_2O abundance present at times with factors of two to three common. This patchiness or horizontal inhomogeneity is probably present along any linear region sampled by the spectrograph slit making a comparison with the average CO_2 abundance along that slit position difficult to interpret.

Another plausible explanation for the lack of correlation is the H_2O variations may be governed by a completely different mechanism than the one which drives observed relative CO_2 line strength fluctuations. Such a mechanism may be the chemical equilibrium between HF , H_2SO_4 , and H_2O which does not depend at all on the CO_2 abundance in the first approximation.

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FIGURE CAPTIONS

Fig. 1. Correlation diagrams of the H_2O and CO_2 abundance determinations made over the same location on the disk of Venus within one to two hours of each other. For the September 1972 $7820\text{\AA}$ diagram, the open circles refer to data on 25 August 1972 (JD = 2441555.).

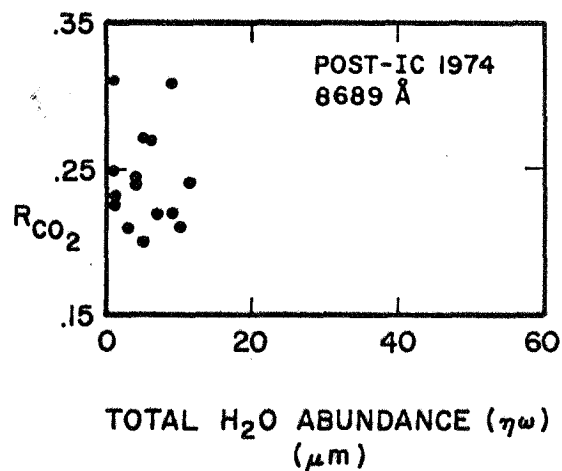
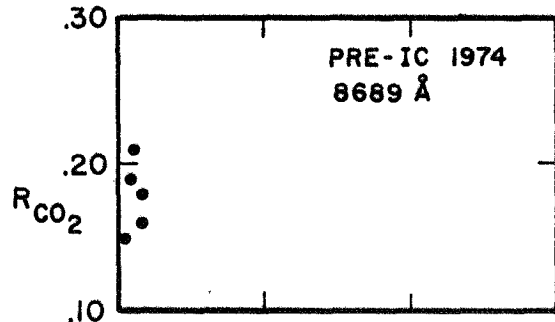
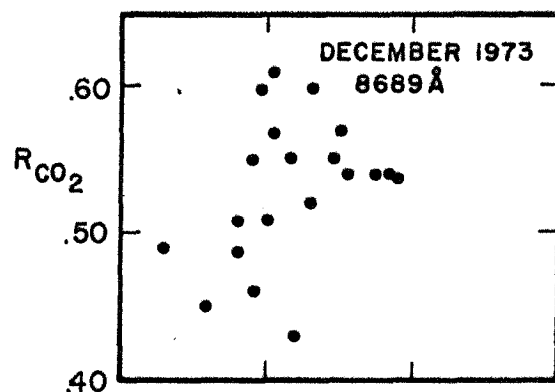
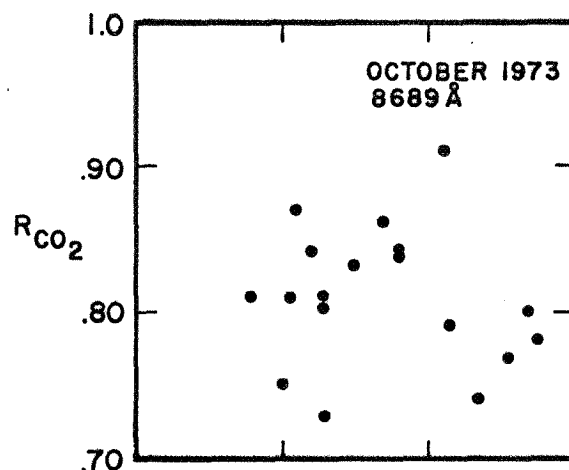
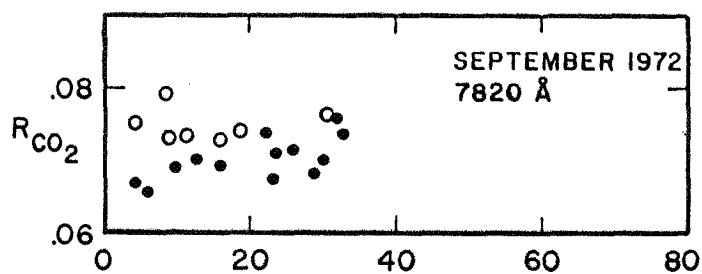
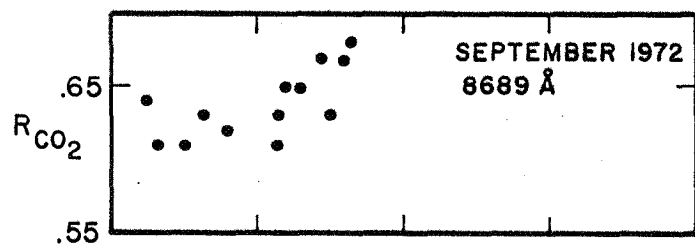
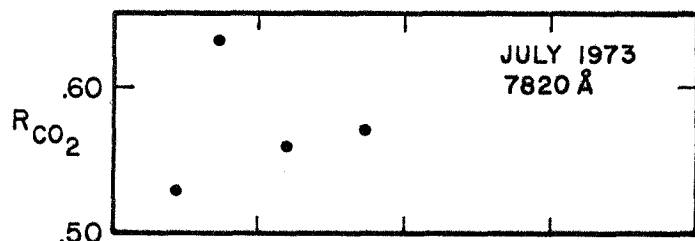
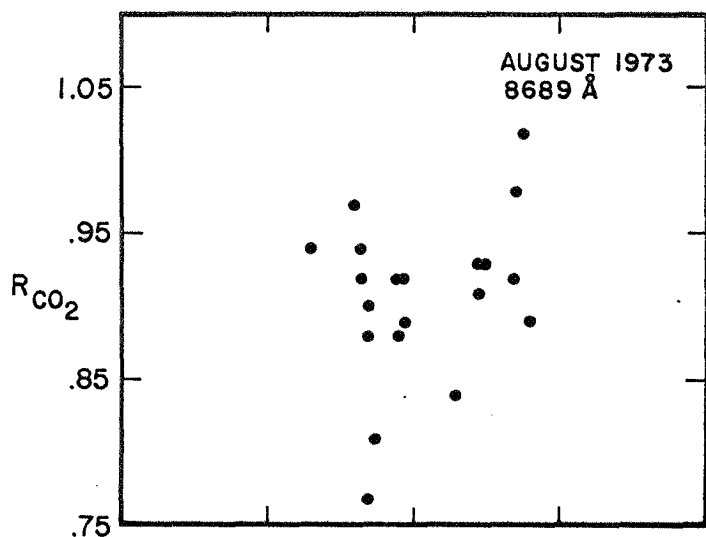


Table 1

CO₂ Line Strengths and H₂O Abundances

CO ₂ Scan ² No. ¹	JD (244-)	R _{CO₂} (☉)	ηω (μm)	H ₂ O Scan ² No. ¹
Aug.-Sept. 1972 7820Å Band-8197Å				
1999 EQ	1555.255	0.07348	13.5	1987 EQ
2000 S/2	1555.262	0.07938	9.0	1989 S/2
2001 N/2	1555.265	0.07330	16.0	1990 N/2
2002 N3/4	1555.275	0.07554	31.0	1995 N3/4
2003 N/4	1555.283	0.07433	19.0	1991 N/4
2004 S/4	1555.287	0.07456	5.0	1992 S/4
2005 S3/4	1555.295	0.07347	9.0	1994 S3/4
2228 EQ	1584.114	0.06665	23.0	2258, 3-5 EQ
2230 N/2	1584.127	0.07438	23.0	2260 N/2
2231 N/4	1584.129	0.06893	10.0	2261 N/4
2232 S/4	1584.136	0.07007	13.0	2262 S/4
2233 S/2	1584.143	0.07017	30.0	2259 S/2
2307 EQ	1587.097	0.06948	16.0	2320 EQ
2309 N/3	1587.107	0.06566	6.0	2324 N/3
2310 S/3	1587.113	0.06729	5.0	2325 S/3
2549 N2/3	1590.206	0.07081	26.0	2535 N2/3
2550 N/3	1590.211	0.07567	32.0	2536 N/3
2551 EQ	1590.214	0.06823	29.0	2534 EQ
2552 S/3	1590.218	0.07419	33.0	2537 S/3
2553 S2/3	1590.218	0.07070	24.0	2538 S2/3
Aug.-Sept. 1972 8689Å Band-8197Å				
2219 EQ	1584.063	0.61426	23.0	2258, 3-5 EQ
2221 N/2	1584.072	0.63091	23.0	2260 N/2
2222 N/4	1584.075	0.60974	10.0	2261 N/4
2223 S/4	1584.078	0.63195	13.0	2262 S/4
2224 S/2	1584.083	0.63338	30.0	2259 S/2
2315 EQ	1587.152	0.61911	16.0	2320 EQ
2317 N/3	1587.152	0.61130	6.0	2324 N/3
2318 S/3	1587.152	0.64004	5.0	2325 S/3
2544 N2/3	1590.178	0.64707	26.0	2535 N2/3
2545 N/3	1590.181	0.67163	32.0	2536 N/3
2546 EQ	1590.184	0.67367	29.0	2534 EQ
2547 S/3	1590.191	0.68010	33.0	2537 S/3
2548 S2/3	1590.191	0.65281	24.0	2538 S2/3

Table 1 (Cont.)

CO₂ Line Strengths and H₂O Abundances

CO ₂ Scan ² No. ¹	JD (244-)	R _{CO₂} (°)	$\eta\omega$ (μm)	H ₂ O Scan ² No. ¹
July 1973 7820Å Band-8197Å				
3936 CD	1871.480	0.56150	24.0	3862 CD
3939 EQ	1871.480	0.56676	35.0	3859 EQ
3940 S/2	1871.480	0.63441	15.0	3860 S/2
3941 N/2	1871.480	0.53450	9.0	3861 N/2
August 1973 8689Å Band-8197Å				
4319 EQ	1905.145	0.93034	48.6	4327 EQ
4321 EQ	1905.240	0.91136	48.6	4327 EQ
4398,9 S/2	1907.300	0.84200	43.4	4392 S/2
4452 EQ	1909.270	0.89444	56.4	4446 EQ
4453 N/3	1909.270	0.88253	37.6	4447 N/3
4454 S/3	1909.270	0.87845	76.6	4448 S/3
4486 EQ	1910.300	0.97848	54.5	4475 EQ
4487 EQ	1910.380	0.92136	54.5	4475 EQ
4488 N/3	1910.380	0.89810	33.5	4476 N/3
4489 S/3	1910.380	0.93694	25.5	4477 S/3
4490 S2/3	1910.380	0.92018	38.6	4478 S2/3
4491 N2/3	1910.380	0.81067	35.3	4479 N2/3
4506 EQ	1910.530	1.02281	55.0	4475 EQ
4507 S/3	1910.530	0.97131	26.0	4477 S/3
4508 N/3	1910.530	0.88473	34.0	4476 N/3
4510 N2/3	1910.545	0.77499	35.0	4479 N2/3
4511 S2/3	1910.545	0.88579	39.0	4478 S2/3
4574 EQ	1917.230	0.91846	33.3	4599 EQ
4606 CD	1917.558	0.92527	50.3	4603 CD
4607 EQ	1917.558	0.93819	33.3	4599 EQ
October 1973 8689Å Band-8197Å				
4708 EQ	1973.359	0.79653	25.5	4713 EQ
4710 EQ	1973.395	0.80630	25.5	4713 EQ
4711 S/2	1973.395	0.80187	53.7	4714 S/2
4712 N/2	1973.395	0.74478	47.1	4715 N/2
4726 EQ	1975.337	0.80757	20.9	4732 EQ
4727 S/2	1975.395	0.81437	16.0	4735 S/2
4728 N/2	1975.400	0.84121	24.3	4734 N/2
4729 CD	1975.408	0.73141	26.3	4736 CD
4730 TERM	1975.411	0.75110	19.6	4737 TERM

Table 1 (Cont.)

CO₂ Line Strengths and H₂O Abundances

CO ₂ Scan ² No. ¹	JD (244-)	R _{CO₂} (°)	$\eta\omega$ (μm)	H ₂ O Scan ² No. ¹
4758 EQ	1976.319	0.87429	22.3	4771 EQ
4759 CD	1976.345	0.84477	36.1	4767 CD
4761 TERM	1976.357	0.83900	36.0	4768 TERM
4794 EQ	1977.309	0.91840	42.3	4805 EQ
4795 S/2	1977.306	0.86052	34.4	4806 S/2
4796 N/2	1977.311	0.76855	51.2	4807 N/2
4797 CD	1977.317	0.82550	29.5	4802 CD
4798 TERM	1977.320	0.77832	54.8	4803 TERM
4799 WLIMB	1977.324	0.79021	47.7	4804 LIMB

December 1973 8689Å Band-8197Å

4914 EQ	2026.314	0.54111	30.7	4925 EQ
4915 N2/3	2026.314	0.49121	7.6	4926 N2/3
4916 N/3	2026.314	0.55146	22.7	4927 N/3
4917 S/3	2026.314	0.53569	38.0	4928 S/3
4918 S2/3	2026.314	0.60507	21.2	4929 S2/3
4919 CD	2026.314	0.54926	17.8	4930 CD
4920 L/2	2026.314	0.51504	26.3	4931 L/2
4921 T/2	2026.314	0.57341	20.9	4932 T/2
4951 CD	2027.460	0.44689	12.0	4955 CD
4952 EQ	2027.460	0.46357	17.6	4956 EQ
4953 S/3	2027.460	0.43465	24.1	4957 S/3
4954 N/3	2027.460	0.48561	16.3	4958 N/3
4972 CD	2028.369	0.57116	29.5	4982 CD
4973 EQ	2028.369	0.60000	26.3	4983 EQ
4974 S/3	2028.369	0.59932	18.9	4985 S/3
4975 N/3	2028.369	0.54173	37.2	4984 N/3
5034 EQ	2030.456	0.53834	35.2	5044 EQ
5035 N/3	2030.456	0.51395	20.6	5045 N/3
5036 S/3	2030.456	0.54572	28.6	5046 S/3
5039 CD	2030.456	0.50817	16.3	5047 CD

Pre-Inf. Conj. 1974 8689Å Band-8197Å

5118 CCS22	2062.290	0.19089	1.3	5129 CCS22
5121 CCN45	2062.290	0.20564	2.4	5132 CCN45
5146 CCEQ	2063.210	0.18046	0.6	5152 EQ
5147 CCS22	2063.210	0.18046	3.2	5153 CCS22
5149 CCN22	2063.210	0.16212	2.9	5154 CCN22

Table 1 (Cont.)
 CO_2 Line Strengths and H_2O Abundances

CO_2 Scan ² No. ¹	JD (244-)	R_{CO_2} (°)	$\eta\omega$ (μm)	H_2O Scan ² No. ¹
Post-Inf. Conj. 1974 8689Å Band-8197Å				
5322 CCEQ	2078.150	0.23465	1.2	5333 EQ
5326 CCN22	2078.150	0.21071	2.6	5335 CCN22
5369 CCN22	2078.180	0.21046	10.1	5381 CCN22
5393 CCEQ	2081.160	0.22643	1.3	5402 EQ
5394 CCS22	2081.160	0.27387	4.9	5403 CCS22
5396 CCN22	2081.160	0.22335	7.3	5405 CCN22
5427 CCEQ	2082.150	0.24088	10.7	5435 EQ
5428 CCS22	2082.150	0.30842	8.7	5437 CCS22
5430 CCN22	2082.150	0.19684	4.9	5438 CCN22
5453 CCEQ	2083.150	0.23818	3.6	5463 EQ
5454 CCS22	2083.150	0.31291	1.2	5464 CCS22
5456 CCN22	2083.150	0.22053	8.6	5465 CCN22
5517 CCEQ	2086.050	0.25147	1.2	5529 EQ
5518 CCS22	2086.050	0.24230	3.6	5531 CCS22
5519 CCN22	2086.050	0.27108	5.6	5530 CCN22

¹ Slit positions: Parallel to intensity equator at various fractions of disk diameter toward poles; N3/4, N2/3, N/2, N/3, N/4, EQ, S/4, S/3, S/2, S2/3, S3/4. Perpendicular to intensity equator or pole to pole at various fractions of disk diameter; T designates terminator, CM--central meridian, CD--center of the disk, L--limb. Along the cord of the crescent at the center of the crescent at various latitudes along the crescent; CC N45, CC N22, CC EQ, CC S22, CC S45.

Table 2
H₂O-CO₂ Correlation Coefficients for
Each Observational Period

Data Set	CO ₂ Band	No. of Pts	r ²	p ¹
August 1972 ³	7820A	20	0.144	<90%
September 1972	7820A	13	0.645	99%
September 1972	8689A	13	0.699	99%
July 1973	7820A	4	-0.019	*
August 1973	8689A	20	0.129	<90%
October 1973	8689A	18	-0.115	<90%
December 1973	8689A	20	0.344	~90%
Pre-Inf. Conj. 1974	8689A	5	0.256	<90%
Post-Inf. Conj. 1974	8689A	15	0.054	*

¹p is the % confidence that the observed correlation is not a random number correlation.

*Much less than 90% level, no correlation.

²Correlation coefficient

³Includes 25 August 1972

Table 3

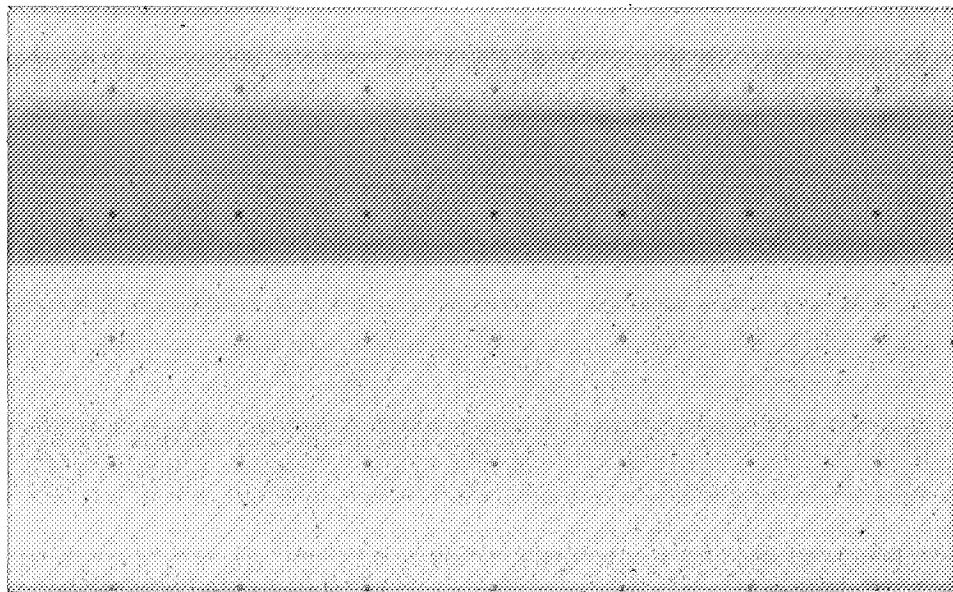
H₂O-CO₂ Correlation Coefficients for Each Day
Having Three or More Pairs of Observations

Date	JD (244-)	No. of Pts.	r	p ¹
7820Å CO ₂ Band				
08/25/72	1555	7	-0.059	*
09/25/72	1584	5	0.164	*
09/26/72	1587	3	0.867	<90%
09/29/72	1590	5	0.651	<90%
07/06/73	1871	4	-0.019	*
8689Å CO ₂ Band				
09/25/72	1584	5	0.473	<90%
09/26/72	1587	3	-0.338	*
09/29/72	1590	5	0.890	95%
08/15/73	1909	3	-0.266	*
08/15/73	1910	6	0.392	<90%
08/15/73	1910	5	0.409	<90%
08/22/73	1917	3	-0.176	*
10/19/73	1973	4	-0.406	*
10/19/73	1975	5	0.281	*
10/20/73	1976	5	-0.987	90%
10/21/73	1977	6	-0.548	<90%
12/09/73	2026	8	0.169	*
12/10/73	2027	4	-0.379	*
12/11/73	2028	4	-0.913	90%
12/13/73	2030	4	0.878	<90%
01/15/74	2063	3	0.797	<90%
02/02/74	2081	3	0.061	*
02/03/74	2082	3	0.548	*
02/04/74	2083	3	-0.856	<90%
02/07/74	2086	3	0.630	*

¹P is the % confidence that the observed correlation is not a random number correlation.

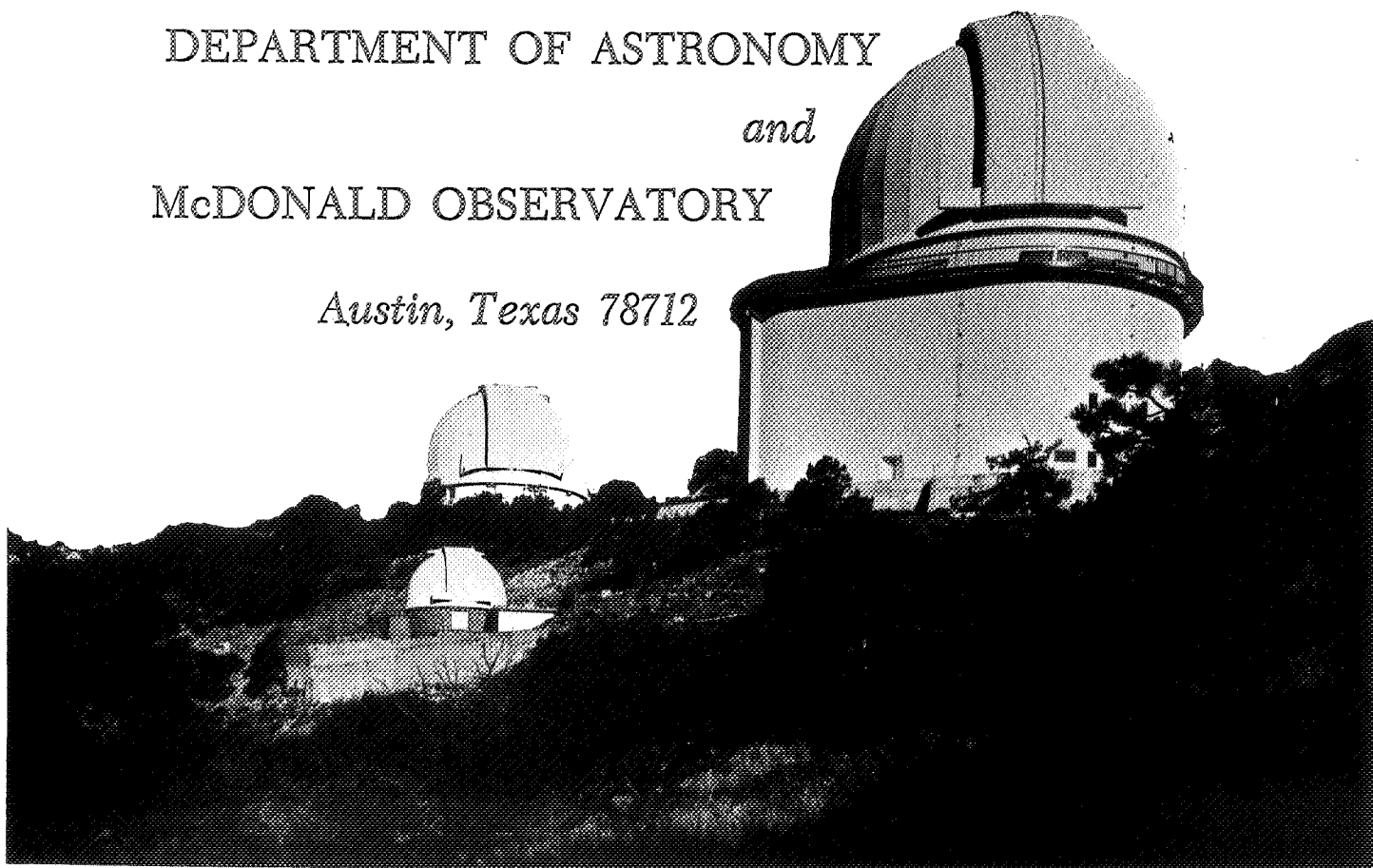
*Much less than 90% level, no correlation.

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Relative Spectrophotometry of Venus
from 3067 to 5960Å

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ABSTRACT

The relative spectral reflectivity from 3067Å to 5960Å for the integrated disk of Venus is presented. The reflectivity is essentially flat from 5960Å to about 5200Å then decreases smoothly to a flat region between 3950Å and 3400Å at 55% of the value at 5960Å. Below 3300Å the reflectivity appears to drop again to possibly another flat region between 3200Å and 3100Å.

Temporal changes in the reflectivity curve are of the same magnitude as the changes over a range of phase angle from 40° to 76°. These changes appear to be only in the amount of UV absorption and not in the shape of the reflectivity curve. The narrow band data of Irvine, *et al.* (1968) is compared to the average reflectivity curve.

The relative reflectivity curve of a dark UV feature compared to a bright UV feature has the same shape as the curve for the integrated disk of Venus. The comparison of these two curves leads to the conclusion that at least a significant amount of the UV absorption must occur above even the bright UV features.

1. Introduction

The geometrical albedo for the near UV portion of the Venus spectrum has been observed in terms of broad band UVB observations (1000Å) of Knuckles, et al. (1961) and narrow band observations (100Å) of Irvine, et al. (1968), Irvine (1968) and Glushneva (1969). The spectral nature or contrasts of the UV clouds was observed by Coffeen (1971) using narrow band (100Å) interference filters and by Woodman and Barker (1973) using the coude spectrum scanner of the 2.7m telescope at 10Å resolution from 3300 to 5100Å. This paper extends the latter program to include observations of the spectral reflectivity of the integrated disk of Venus from 3067 to 5960Å. In order to remove any secondary calibration, both the Sun and Venus were observed with the same instrumental setup within hours of each other.

2. Observations and data reduction

The observations were made using the rapid coude scanner of the 2.7m telescope (Tull, 1972). The coude scanner was used in the grating scanning mode using a dry ice cooled RCA 31034A photomultiplier as the detector and a grating blazed at .41μ in first order. Due to the intensity falloff in the solar spectrum, atmospheric extinction and system response, the counting rate varied by at

least three orders of magnitude between 3100 and 5000Å. In order to keep the counting rates on the Sun down to non-coincidence levels, the entrance slit was narrowed to 0.5mm with the exit slit set equivalent to 2.5Å. Each channel in the spectrum represents about a 10Å bandpass.

The integrated spectrum of Venus and the spectrum of the center of the Sun were obtained by placing a diffuser and aperture at the focus of the f/33 coude beam, but in front of the slit. The size of the aperture was just slightly larger than the diameter of Venus and placed at a distance in front of the slit to subtend a f/33 beam at the slit. The diffuser used for the September 1973 observations was replaced with one with higher UV transmission for the 1974 observations.

To remove the effects of the sky background which was about 30% of the Venus plus sky signal at 3500Å, a sky observation of equal time duration was made before and after each Venus and Sun observation, then averaged and subtracted from the respective Venus plus sky spectrum or Sun plus sky spectrum.

The observations of the center of the Sun were made using a polyurethane screen as a mask in front of the 2.7m telescope. Four one-inch holes were cut in the screen midway between the secondary mirror and the outer edge of the primary mirror and midway between the support vanes of the

secondary mirror. These four one-inch apertures provided a sampling of different areas of the coude optics in order to match the reflectivity of the entire coude optical system.

By observing Venus and the Sun with essentially the same optical system, a simple ratio spectrum between Venus and the center of the Sun removes all of the system reflectivity and sensitivity parameters, leaving only the reflectivity of the Venus atmosphere and clouds relative to the center of the Sun.

The correction of the different atmospheric extinction between the Venus and Sun observations was obtained by two methods. Using the method described by Barker and Trafton (1973), the scans of the Sun were used to create a spectrum of the Sun for each airmass corresponding to a Venus scan. Then ratios were taken between the Venus spectrum and extinction produced solar spectrum. Since the observations of both Venus and the Sun were made at or near transit, the range in the airmass of the Sun was very small (less than 0.10) resulting in an extinction solution not as well determined as one would prefer. Also, any imperfection in any of the solar spectra were transmitted to the Venus/Sun ratio causing false features in the ratio spectrum. The imperfections (at the 5% level of accuracy) in the solar spectra were noted as a systematic difference

in the forward and reverse scans due to a change in count rate during one or more of the scan cycles. The count rate fluctuations were due to changes in the illumination of the optical system caused by wind rippling the surface of the Sun screen. If the bad solar scans were rejected, the number of good solar scans was reduced to two or less for several days, consequently not allowing extinction solutions to be calculated for those days.

Similar ratio spectra were obtained by a second method of reduction. This method allowed us to select the solar scans which were free of the wind-caused counting rate changes. All the good Venus and solar scans on a particular day were combined to produce an average Venus or solar scan for that day. The average airmass values for the Venus and Sun scans were also calculated by weighting the airmass for each individual scan by the maximum number of counts in the scan. Using the general formula for atmospheric extinction due to Rayleigh scattering and ozone absorption scaled to the elevation of McDonald Observatory, a theoretical extinction curve was calculated for the airmasses of the Venus and Sun observations. Then a ratio between the respective theoretical curves was calculated and applied to the Venus/Sun ratio spectrum to remove the effects of the difference in atmospheric extinction between the Sun and Venus observations.

All of the observations were made on very clear, blue sky days at McDonald and usually during a three to four hour period near transit of Venus and the Sun. No changes in the terrestrial atmosphere were noted during the days for which we are presenting a final ratio spectrum. The physical parameters for Venus are given in Table 1 for each day we have produced a final ratio spectrum.

3. Venus UV reflectivity

The upper ratio spectrum in Figure 1 shows actual Venus/Sun ratio spectrum for 3 May 1974. The noise in the ratio spectrum has several causes: (1) The general increase in the noise level going toward the UV end is due primarily to the decrease in the count rate from Venus. (2) Part of the general noise is due to the mismatch of the observed wavelengths caused by the Doppler shift differences of about $.3\text{\AA}$. (3) The positive spikes are due to the filling in of the solar lines in the integrated solar spectrum compared to the solar lines from the center of the Sun. In order to improve the appearance of the spectrum, especially at the UV end of the spectrum, a running mean smoothing technique was applied to the raw ratio, reducing the effective resolution to $40\text{\AA}$ instead of the $10\text{\AA}$ in the raw data. The resultant smoothed spectrum is much cleaner especially at the UV end, although it still contains the

effects of the positive spikes at the strong solar lines (primarily the Ca H and K lines, $H\gamma$, $H\beta$ and the Mg II triplet at 5184Å).

The final ratio spectra smoothed to 40Å resolution are shown in Figures 2 and 3 for all seven dates given in Table 1. All spectra show a decrease to a plateau ~3400-3900Å than a further decrease below 3300Å.

The spectrum obtained on 13 September 1973 is by far the noisiest and does not cover the entire wavelength range. This observation was the first attempt at this type of observation and is presented here only for completeness although the general shape of the decrease in the UV reflectivity is the same as the other six ratio spectra.

Imperfections present in the Sun scans on 1 May 1974 at 5800Å and on 8 June 1974 between 4400Å and 4800Å show up in the final ratio spectra. It was impossible to remove these from the data unless a solar scan from another day was used. All of the 1974 scans will fall on top of each other, when the photometric errors of 5% at the red end and 15-20% errors at the extreme UV end are considered. If all the scans are normalized at 5960Å, all other scans deviate less than 15% from the mean scan. Any feature over a small wavelength range with a relative depth less than 5% at the red end or 20% at the UV end cannot be trusted because of the photometric uncertainties introduced by the rippling

Sun screen.

Figure 4 illustrates the observed changes with time for 1 May versus 3 May and with phase angle for $75^{\circ}8$ and $39^{\circ}6$. The differences are similar in magnitude, consequently any change attributed to a difference in phase angle can more easily be explained in terms of the daily changes. These daily changes are probably due to a change in the percentage of the disk over which dark UV clouds are present. Glushneva (1969) also noted the variability of the shape of the reflectivity curve with the presence of UV markings, but her photographic data were not as accurate as the present photoelectric data. Since the ratio spectra in Figures 2 and 3 are very nearly identical and do not show any large systematic differences with phase angle, all the 1974 ratio spectra can be averaged into one Venus reflectivity curve.

Ultraviolet photographs of Venus were attempted on most of the dates listed in Table 1 at the coude focus of the 2.7m telescope. The photographs did not show any distinct UV features primarily because less than optimum seeing existed before and after the three to four hour period required to obtain the photometric scans of Venus and the Sun. The International Planetary Patrol Program based at Lowell Observatory was able to provide photographs during the observational periods but only on two days (3 May and 4 June 1974) do we have both photographs and photometric scans.

On these days the broad, diffuse "Y" feature was present covering approximately 50% of the disk of Venus. Photographs on days (12 September 1973; and 2, 9, 11 May and 8 June 1974) showed a similar amount of UV features on the disk.

The two main features present in all the 1974 ratios reduce to the only features when all the smoothed ratios are summed together as shown in Figure 5. The general smooth falloff toward the UV end begins about 5200Å. The decrease continues smoothly to a flat region between 3400Å and 3950Å at the 55% level. Below 3300Å the reflectivity appears to drop again to possibly another flat region between 3100Å and 3200Å. The relative magnitude of this second decrease varies between a maximum of 50% on 10 May 1974 and 20% on 12 May 1974. This feature is real and does repeat from scan to individual scan, but the number of counts are so low below 3200Å that a varying number of channels between 3000Å and 3067Å have been dropped in the Venus scans due to excessive noise in the ratio spectra. The spectra probably do not turn up at the extreme UV end and any apparent turnup is only an artifact of the noisy ratio spectra. The sum of the ratio spectra presented in Figure 5 contains only channels which are common to all ratios. Additional observations between 2800Å and 3300Å are needed to provide a continuous overlap of the ground-

based reflectivity curve and the Orbiting Astronomical Observatory (OAO) observations of Wallace, et al. (1972) in order to test the reality of this second absorption feature at 3100Å. Observations providing this overlap have been made in the form of the rocket data of Anderson, et al. (1969) and are discussed in the context of Figure 7.

Since the ratio spectra we have obtained are with respect to the spectrum of the center of the solar disk, a correction must be made to produce an integrated solar spectrum which we are observing in the case of Venus. This has been accomplished by using the continuum intensity ratios for the center of the Sun and integrated disk (I_D/I_C) given by Labs and Neckel (1968) in their Table 2. A smooth interpolated correction factor (I_D/I_C) was calculated for the wavelength corresponding to each channel in the sum ratio spectrum and the resultant corrected spectrum appears in the upper curve in Figure 5. This corrected spectrum represents the final stage of processing and is used exclusively in the rest of the paper.

The observations made by Irvine, et al. (1968) of the relative spectral reflectivity of Venus at phase angles of 40° and 100° are plotted in Figure 6 along with our corrected sum ratio spectrum. These narrow band observations and a smooth extrapolation of the Venus

reflectivity curve have been arbitrarily normalized at 6264Å. The narrow band observations show a bluer Venus at larger phase angles where as we do not see a significant variation over our phase angle range of 40° to 76° that cannot be explained by a variation in the percentage of the disk covered by UV features. The narrow band data shows a disappearance of the 3500Å plateau between 40° and 100° phase angles. This plateau appears constant over our range of phase angle indicating either the narrow band point at 3926Å at 100° phase angle is too high or a significant change in reflectivity must occur between 76° and 100° phase angle. The general fit is quite good below 4200Å, but the narrow band points at 5012Å and 4573Å are completely inconsistent with our observed smooth variation between 4500Å and 5960Å. For this reason, we have not normalized to the 5012Å point and believe it may be 10-15% too low.

The plateau of the Irvine (1968) data between 4500Å and 5000Å was used by Kuiper (1969) and discussed by Cruikshank and Thompson (1971) as a diagnostic feature to interpret the spectral reflectivity of the Venus clouds in terms of $\text{FeCl}_2 \cdot 2\text{H}_2\text{O}$ particles. Any evidence for $\text{FeCl}_2 \cdot 2\text{H}_2\text{O}$ absorption around 5000Å in the reflectivity curve is not present in our data.

The longest wavelength observed on Venus by Wallace,

et al. (1972) in the OAO data was at 3000Å due to the extreme intrinsic brightness of Venus. They simply adjusted their data to smoothly fit Irvine (1968) at 3147Å. Because of the difficulties of doing accurate photoelectric photometry at 3000Å, we do not overlap the OAO data, but it must be done to determine the reality of the feature at 3100-3200Å. The Irvine (1968) data provides partial confirmation of this feature because of the placement of the 3147Å and 3950Å filters. The 40° phase angle data show more of a decrease at the 3147Å point than the 100° phase angle data. Only continuous data can show the detailed nature of any of the absorption bands.

In Figure 7 we have presented our average reflectivity curve in comparison to the various sources of far UV data below 3000Å. The rocket photographic data of Evans (1967) and the rocket photoelectric data from Anderson (1969) have been normalized to the 3147Å point of Irvine (1968) for a phase angle of 76°. Since the photoelectric data from the OAO satellite (Wallace, 1972) did not overlap the Irvine data their 3000Å point was placed at the same level as the 3147Å point of Irvine (1968). There is strong disagreement between the slope of the reflectivity below 3000Å, consequently we cannot say anything about the blue side of the 3100Å feature in our data. The more reliable OAO data could be adjusted vertically to fit our short wavelength point at

3067Å inferring the UV absorption decreases below 2950Å or the albedo increases. If we believe the rocket data, the UV absorption must continue to increase below 3000Å which is the opposite conclusion. Clearly additional spacecraft data must be obtained in the region (2800-3400Å) to provide a good overlap. Obviously, ground-based data must be obtained on the same day.

4. Relative reflectivity of Venus clouds

The comparison of the relative reflectivity between a dark UV region and a bright UV region on 10 September 1972 (Woodman and Barker, 1973) and the reflectivity of the total disk is made in Figure 8. The UV feature was a very prominent broad, equatorial band compared with the bright polar regions. The similarity in the shapes of the reflectivity curves is very strong over the wavelength region common to both curves. The integrated disk curve appears to be only an enhanced absorption. The fact that at 3200Å we see only a maximum value of 40% contrast differences between dark and bright UV regions (Coffeen, 1971; Woodman and Barker, 1973) and a 55% contrast difference for the entire disk means the UV absorber must also be present above the bright UV regions if half the planet is covered with dark UV features having an intrinsic contrast of 40%. The dark UV features must also be at the same level or lower in the atmosphere than the bright UV regions. The later

conclusion is also supported by the increased polarization over the UV regions measured by Mariner 10 (Hapke, 1974).

5. Venus near infrared reflectivity

With the hope of extending the Venus reflectivity curve from 6000Å to 12000Å, we obtained photoelectric spectrum scans in a manner similar to methods described for the UV scans. The only differences are the use of a FW118 (S-1) photomultiplier and a grating blazed at 0.6μ which resulted in about a 13Å bandpass for each channel. The problem of the wind rippled Sun screen reduced the useful data to only one day, 8 May 1974. The raw unsmoothed ratio spectrum (Venus/Sun) appears in Figure 9 after being corrected for the intensity ratio I_D/I_C for the Sun taken from Labs and Neckel (1968). The accuracy of this ratio spectrum is not better than 5% from the blue end to about 11000Å. Beyond 11000Å contamination by H₂O vapor bands and a low signal make the ratio spectrum extremely noisy and probably not useful.

The reason for including this near infrared observation with the UV data is to show that reflectivity of Venus remains essentially flat between 5200Å and 11000Å. The positions of the Venus CO₂ bands are marked by filled circles and the various telluric absorption bands due to O₂ and H₂O are marked by brackets. The good cancellation of the O₂ absorptions at 6800Å and 7600Å is evident, but the solar

spectrum contained less H_2O absorption although the airmass match was good (1.240/1.302).

Again as for the UV data, we have normalized to Irvine's (1968) point at 6264Å showing data for 40° and 100° phase angle. The decrease of about 8% in the albedo as measured by Irvine (1968) at 10635Å was interpreted by Kuiper (1969) as evidence for dihydrated ferrous chloride particles in the Venus clouds. Cruikshank and Thompson (1971) re-measured the Venus reflectivity in this region from 8000Å to 11000Å and concluded the evidence for a dip between 9000Å and 9600Å was negative. Based only on one good observation of this region, we agree with Cruikshank and Thompson that there is not any evidence for a $FeCl_2 \cdot 2H_2O$ absorption band in this wavelength region.

6. Conclusions

The UV reflectivity curve for the clouds of Venus from 3100Å to 6000Å contains three features: (1) The major decrease begins at 5200Å and drops smoothly to about 3950Å. (2) A flat region at about 55% of the 6000Å value from 3950Å to 3400Å. (3) A second decrease starts at 3300Å dropping another 20 to 50% by 3200Å. The trend of the reflectivity below 3100Å is very uncertain and needs to be resolved.

The phase angle dependence of the reflectivity curve is not greater than the temporal changes in the apparent

amount of the UV absorber. The relative reflectivity curve between bright and dark UV features has the same spectral shape as for the integrated disk but does not decrease to the 55% level implying a significant amount of the UV absorber above the bright UV features.

The lack of any spectral features at 5000Å and 9000Å to 11000Å rules out any evidence for dihydrated ferrous chloride ($\text{FeCl}_2 \cdot 2\text{H}_2\text{O}$) particles in the visible Venus clouds. The shape and depth of the Venus reflectivity curve can be explained by the presence of polymorphic sulfur particles which result from photodissociation of COS above 2200Å. The laboratory analysis supporting this conclusion appears as a companion paper in this issue (Hapke, 1975).

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BAAS 5, No. 2, 301. (Abstract)

FIGURE CAPTIONS

- Fig. 1. Venus/Sun ratio spectrum for 3 May 1974: (a) raw 10Å resolution and (b) smoothed to 40Å resolution. Zero level vertically displaced for clarity.
- Fig. 2. Smoothed Venus/Sun ratio spectra for labelled dates. Zero levels vertically displaced for clarity.
- Fig. 3. Smoothed Venus/Sun ratio spectra for labelled dates. Zero levels vertically displaced for clarity.
- Fig. 4. Comparison of the reflectivity curves on 1 May and 3 May 1974 to illustrate short term temporal changes. Comparison of reflectivity curves on 1 May and 25 July 1974 to illustrate that the long time base which should show phase angle effects produces changes similar to the short term comparison.
- Fig. 5. Sum of ratio spectra on 1, 3, 10, 12 May, 8 June and 25 July 1974. Sum ratio spectrum corrected for the ratio of the integrated solar disk and the center of the disk.

- Fig. 6. Comparison of the Venus reflectivity measurements of this paper and the narrow band data of Irvine, et al. (1968) for phase angles 40° (+) and 100° (o), all normalized at $6264\text{\AA}$. The horizontal bars in the narrow band data represent the full width at half maximum of the filters.
- Fig. 7. Comparison of the Venus reflectivity measurements of this paper and the rocket data of Anderson, et al. (1969) and Evans (1967) and OAO data of Wallace, et al. (1972) normalized to the $3147\text{\AA}$ point of Irvine (1968) at 76° phase angle.
- Fig. 8. Comparison of the reflectivity curve of the integrated disk of Venus and the relative reflectivity of a dark UV feature to a bright UV feature, normalized at $5100\text{\AA}$.
- Fig. 9. Near infrared ratio spectrum of Venus/Sun at 72.5° phase angle corrected to the mean solar disk intensity. Venus CO_2 bands marked by filled circles and regions of telluric absorption by brackets. The narrow band data of Irvine, et al. (1968) for phase angles 40° (+) and 100° (o), all normalized at $6264\text{\AA}$. The horizontal bars in the narrow band data represent the full width at half maximum of the filters.

Table 1

Physical Parameters of Venus Observations

Date	Phase Angle	Seeing	Number of Venus Scans	Number of Sun Scans
09/13/73	61°9	3-4 arcsec	2	1
05/01/74	75°8	3-4 arcsec	3	1
05/03/74	74°9	3 arcsec	3	3
05/10/74	71°6	2-3 arcsec	3	3
05/12/74	70°7	2 arcsec	4	2
06/08/74	58°8	2-5 arcsec	4	2
07/25/74	39°4	2-3 arcsec	3	3

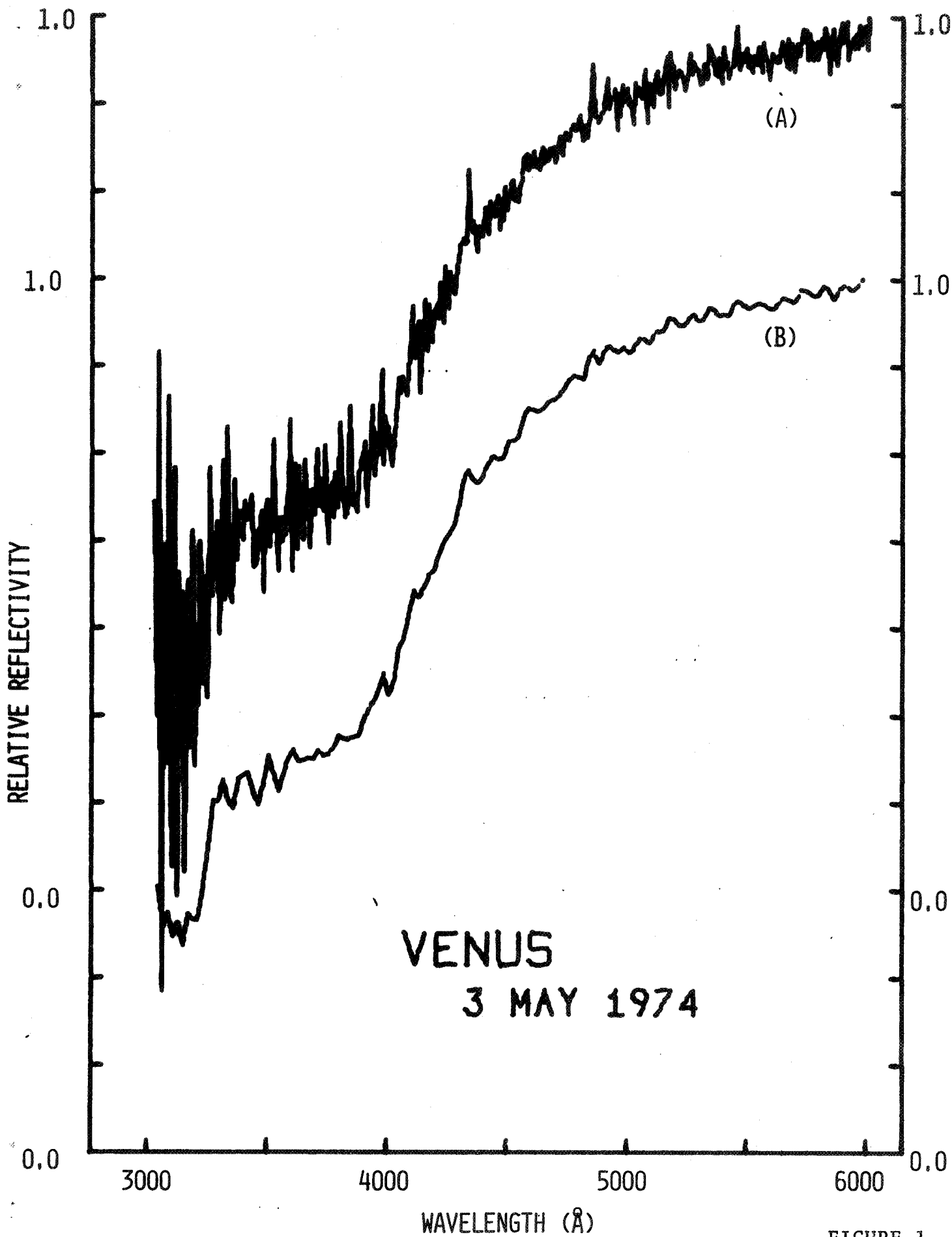


FIGURE 1

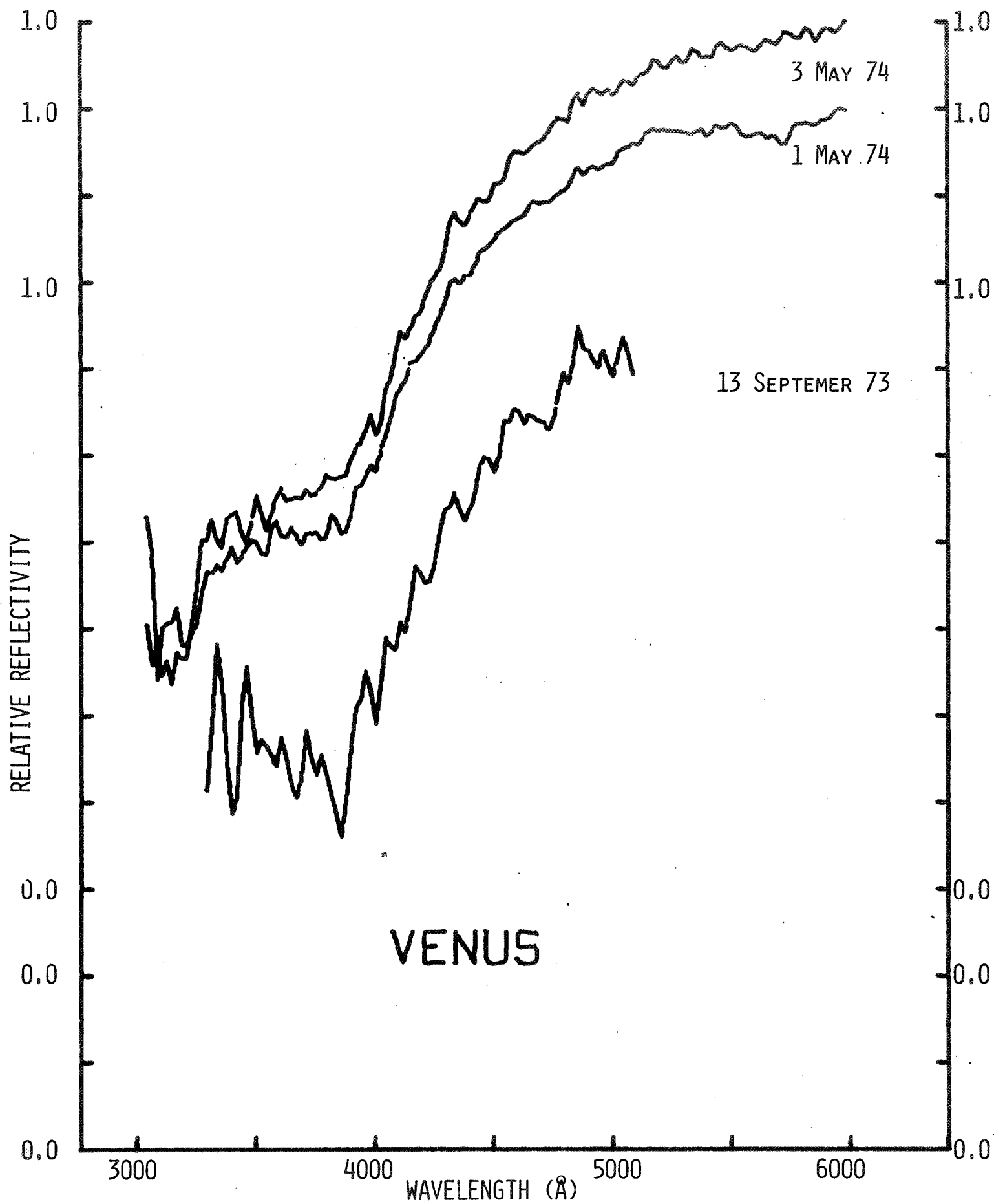


FIGURE 2

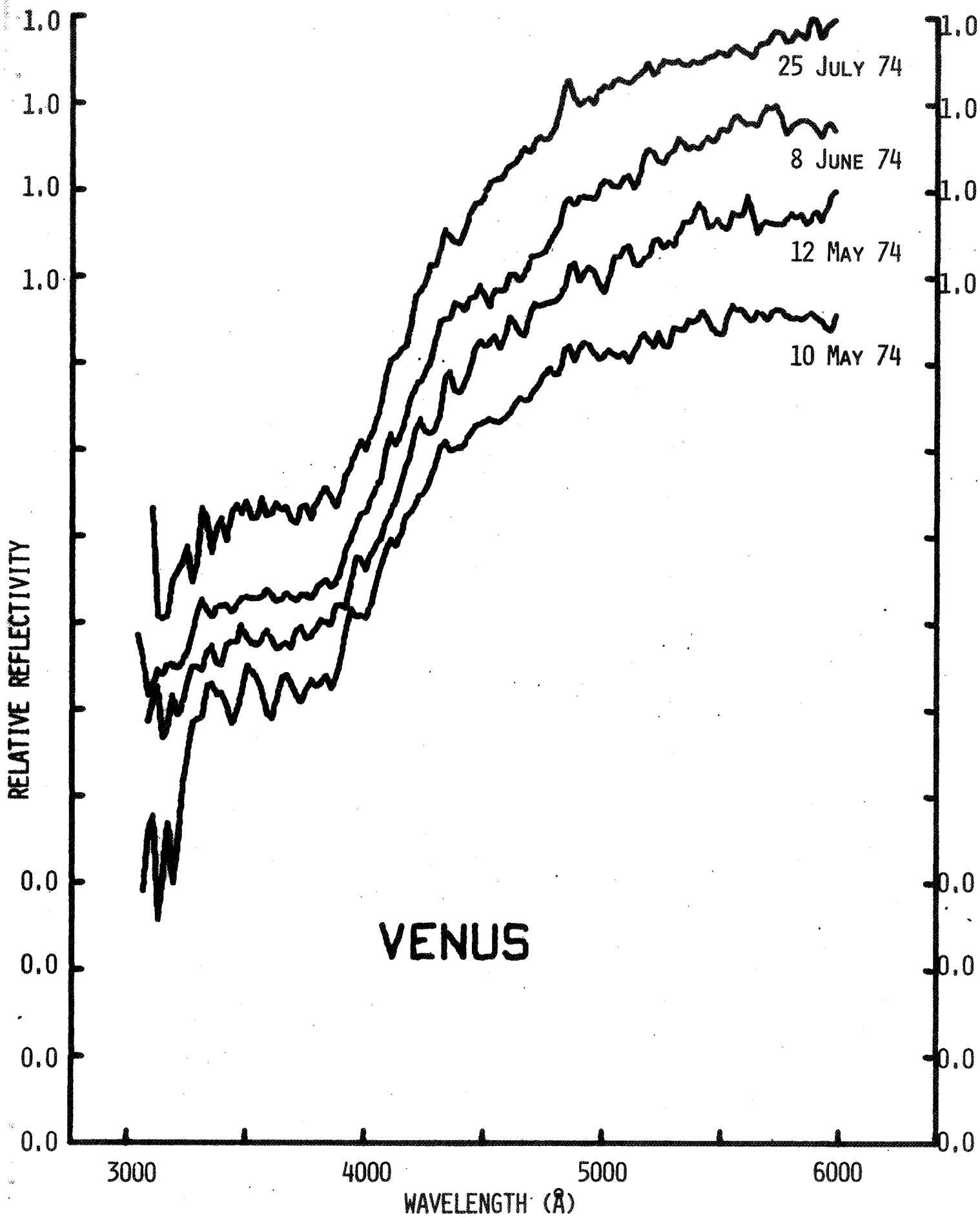


FIGURE 3

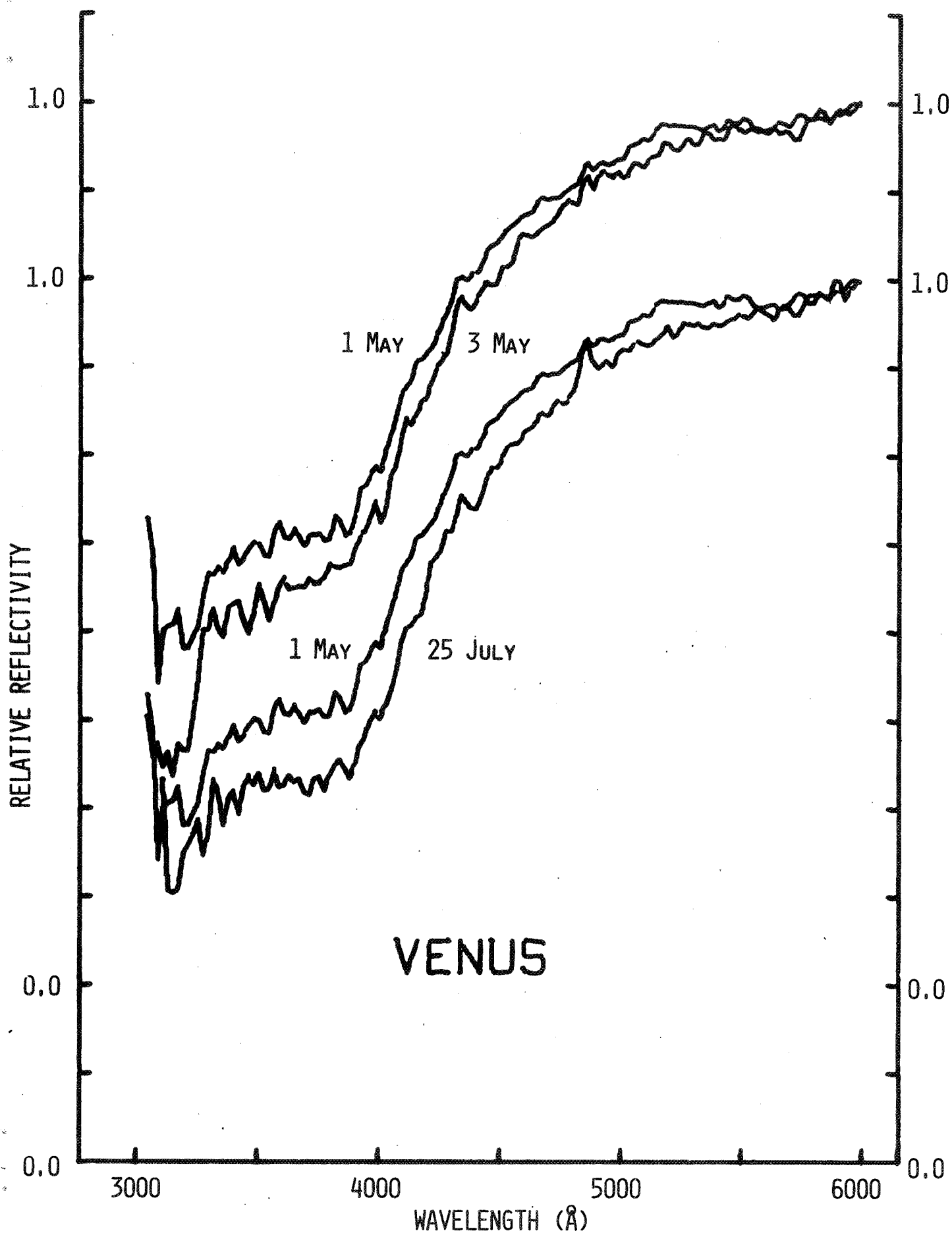


FIGURE 4

VENUS REFLECTIVITY

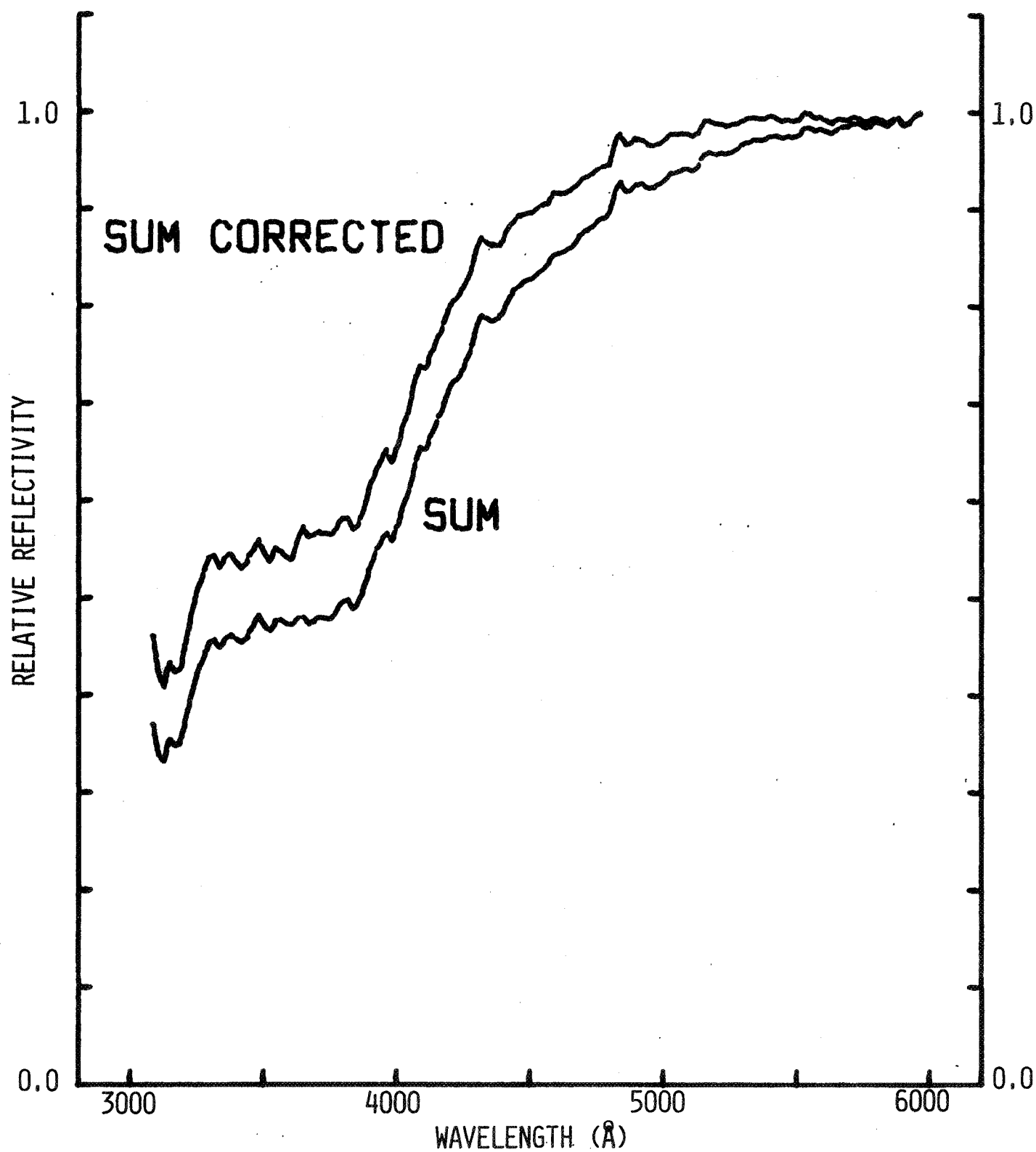


FIGURE 5

VENUS REFLECTIVITY

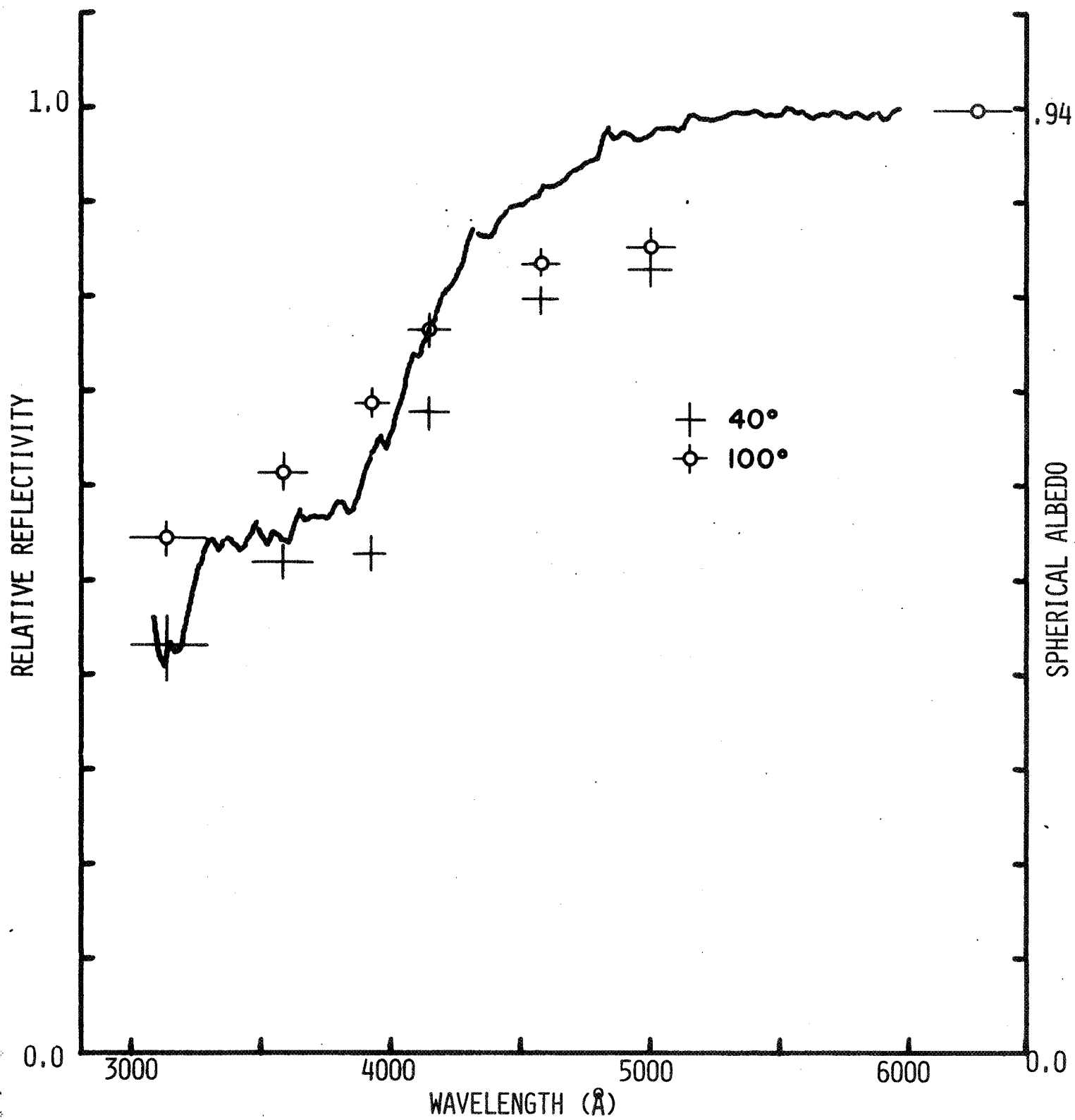


FIGURE 6

VENUS REFLECTIVITY

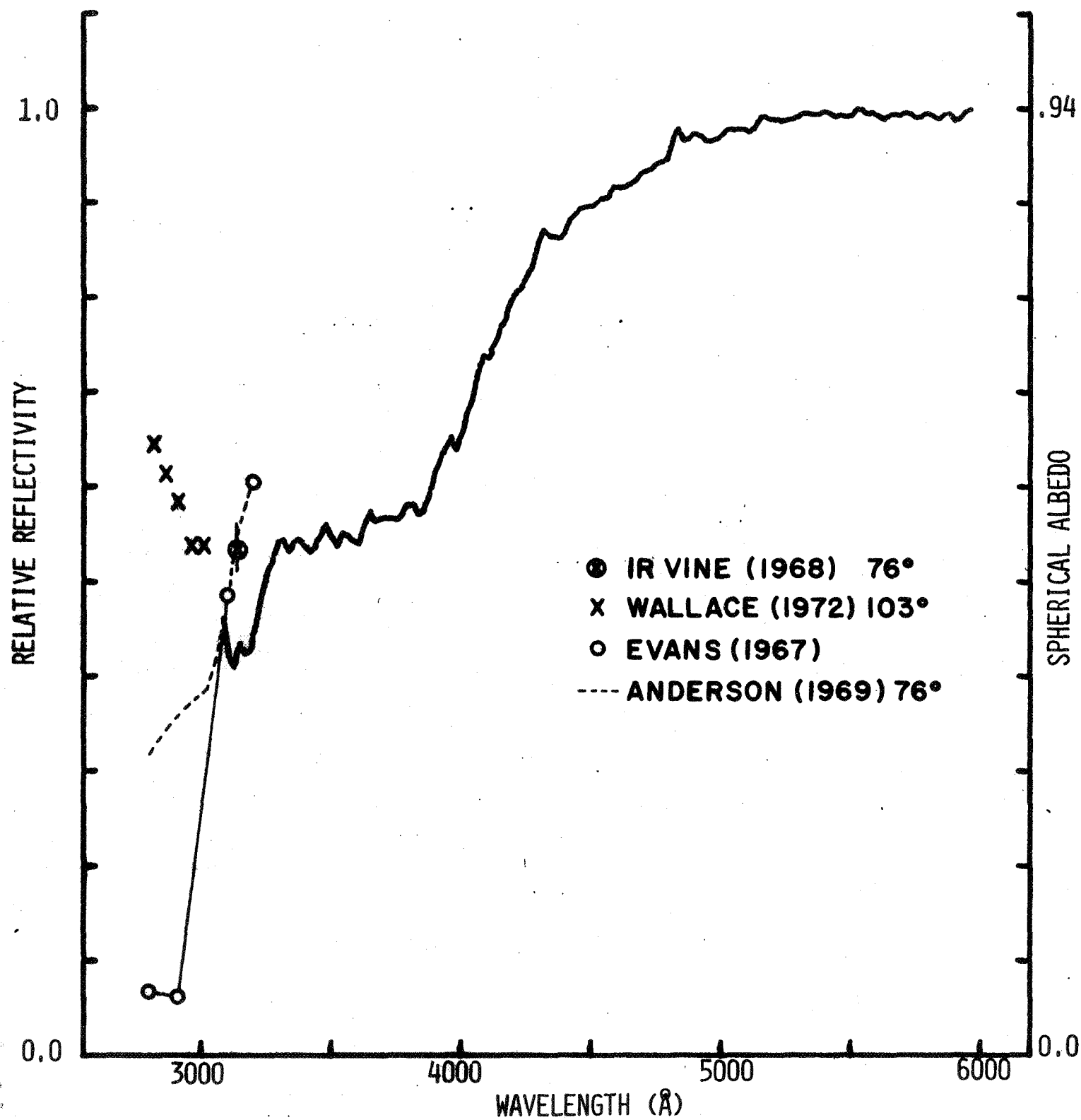


FIGURE 7

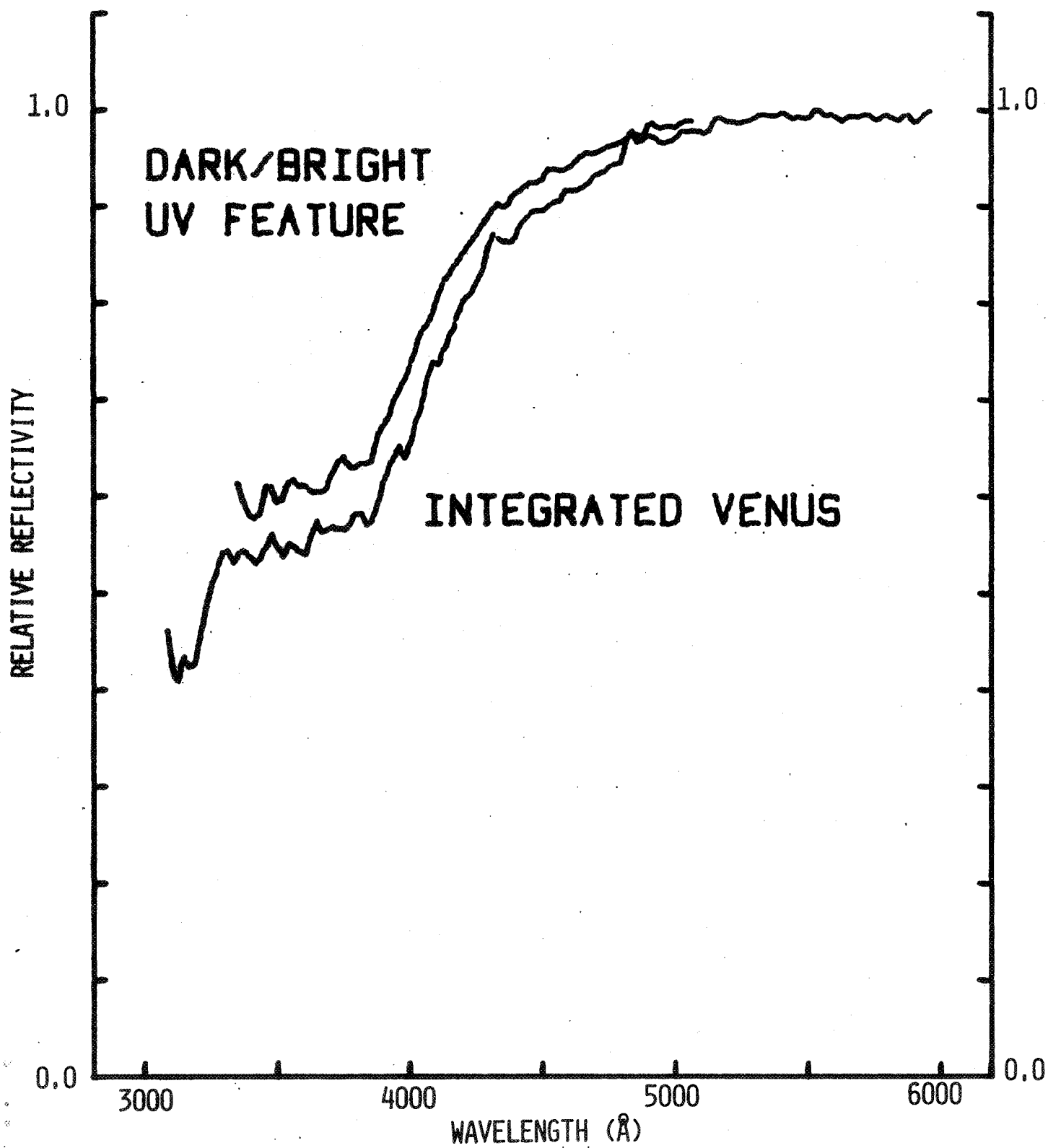


FIGURE 8

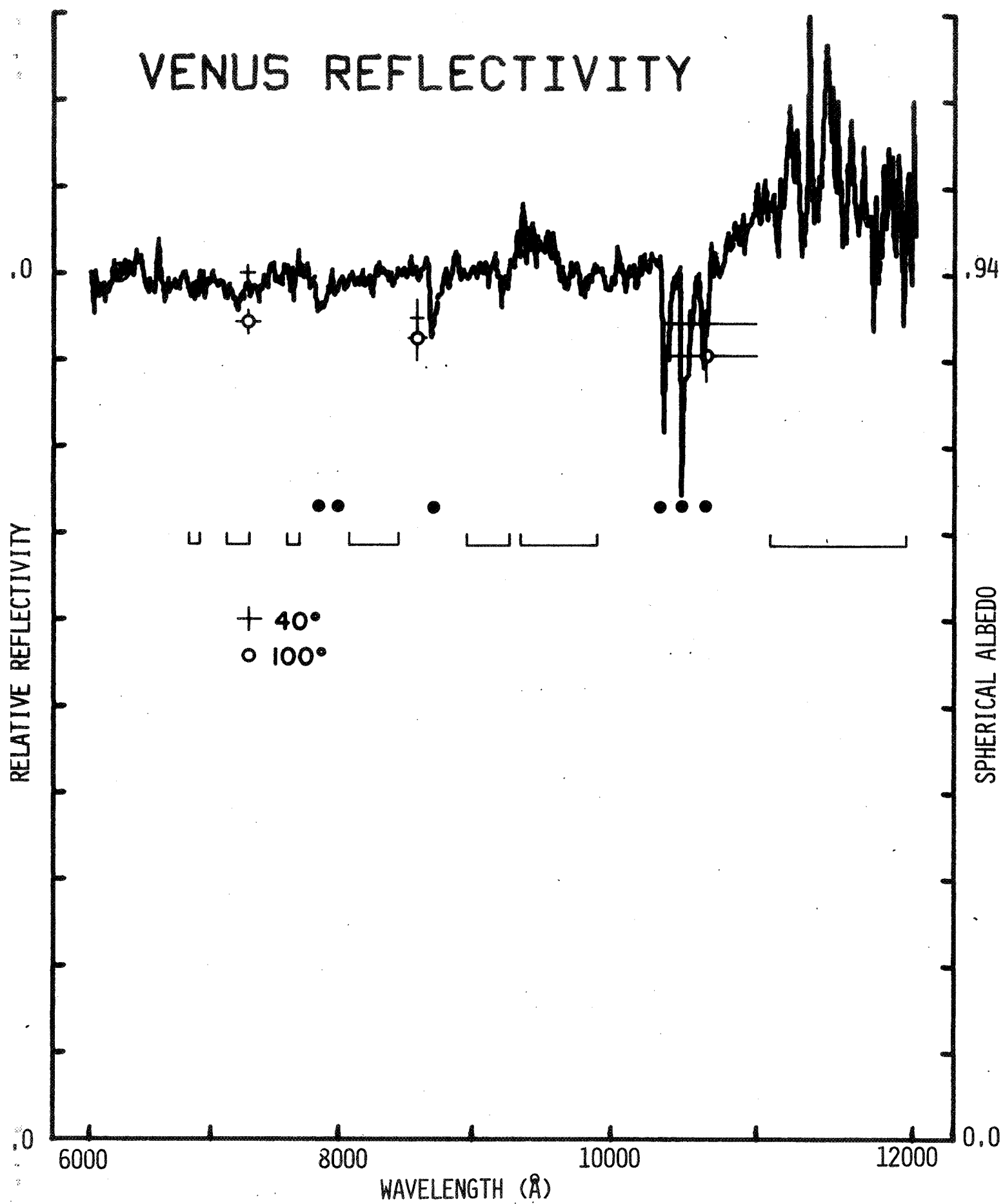


FIGURE 9

Semi-periodic Variations in CO₂ Abundance
on Venus

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ABSTRACT

Photoelectric spectral scans of the P branch of the 8689Å CO_2 band on Venus have been made during seven observing periods in the past two years using the 107-inch coude scanner. The relative CO_2 line strength has been determined for each scan, then normalized to remove the spatial variations leaving only temporal variations.

The four-day periodicity in the relative CO_2 line strength noted by Young, et al. (1973) is not unique; we do confirm their four-day periodicity in August 1973. Four other observing periods rule out a four-day periodicity.

A definite North-South asymmetry in the relative CO_2 line strength is noted during 1973, in most cases with the same periodicity present in both hemispheres. When the slit positions are referred to the equator of Venus, particularly near inferior conjunction, the large asymmetries between the slit positions can be explained by a greater CO_2 line strength over the polar regions and weaker over the equatorial latitudes. The amplitude of variation of each position on the crescent is much greater near inferior conjunction either because we are sampling a smaller area on the planet or the upper atmospheric abundance is more sensitive to the mechanism causing the variation in the smaller regions sampled at inferior conjunction.

Simultaneous H_2O measurements during several of the observing runs indicate a lack of correlation in the relative CO_2 line strengths and the H_2O abundance.

I. INTRODUCTION

We have obtained photoelectric spectral scans of the P branch (P2-P38) of the $8689\text{\AA}$ CO_2 band during seven periods of time over the past two years at McDonald Observatory using the coude scanner of the 107-inch telescope. After observing a four-day periodicity in the CO_2 line strength during September of 1972, both at McDonald and Table Mountain Observatories, we decided to test the uniqueness of periodicity with another series of Venus observations. A major reason for presenting this paper is that we did not find the four-day periodicity to be unique.

II. OBSERVATIONS AND DATA REDUCTION

A total of 251 scans of the P branch have been made using the coude scanner in the wobble mirror-grating mode. The grating scans of moderate resolution ($0.3\text{\AA}$) required about 10 to 15 minutes to reach a precision of 0.5% in the continuum. The resolution was increased to $0.2\text{\AA}$ during the inferior conjunction in 1974 because of the much weaker CO_2 lines.

The slit of the spectrograph was aligned by means of an image rotator using the intensity equator of Venus as a reference. The entrance slit length of the spectrograph was always slightly longer than the image of Venus along the slit. For each observed slit position a ratio between the signal from the

sky and the signal from the sky plus planet was taken to facilitate the removal of the sky contribution which was <5% of the total signal. A spectrum scan of the sky near Venus or of integrated solar disk was obtained immediately before or after each set of Venus observations. This "sky" scan was subtracted from each Venus scan using the planet to sky signal ratio to calculate how much sky contamination to remove. The general slope of the system response with wavelength was removed by dividing the Venus minus sky spectrum by a scan of a white light source made during the set of Venus observations. These scans were reduced by methods similar to those described by Young, et al. (1973) to obtain a relative CO₂ line strength for each scan. This has been done by summing the residual intensities of the CO₂ lines in one scan and normalizing this sum to the residual intensity of the only unblended solar line (Mg I, 8717.833⁰Å, 87mÅ) within the portion of the CO₂ band observed. Generally, the same results have been obtained using only the average CO₂ residual intensity for each scan. The CO₂ residual intensities can be converted into equivalent widths by procedures described in Appendix A. Preliminary results were presented by Barker (1974a).

1 ~~seven~~ even periods of observations can be broken into two types of observations, inferior conjunction and moderate phase angles. We have three sets of observations near inferior conjunction when the phase angle is very large (>150°).

with the spectra taken with the slit as a chord of the thin crescent at various positions north or south of the intensity equator. The other periods of time in September of 1972, August, October and December of 1973, were at smaller phase angles. The observational periods and results are summarized in Table I. The various slit positions are shown schematically on the insert in each figure. The average seeing disk was ~ 2 arcsec. The number of slit positions taken during an observational period is indicative of the maximum number of independent positions we could sample on the disk.

September 1972. Beginning with September 1972 data (Schorn and Barker, 1973) in Figure 1, we see that there is a periodicity in the CO₂ line strength that is roughly four days considering the minima of the observed curve. Insufficient coverage near the beginning of the time period did not allow us to observe on the maxima days as indicated by Young, et al. (1974) (Figure 2). Non-consecutive daily coverage is indicated by a broken line. We have used the equatorial slit position as our standard position and the other slit positions on a particular day have been normalized to the equatorial position of that day to determine any asymmetry in the North-South direction. Each scan is normalized to the equatorial scan of that day and then a mean value was determined for the entire run for observations of a particular slit position, such as the North two-thirds. Then this mean has been applied to the daily position (such as North two-thirds position) to bring it into closer agreement with the equatorial measurement for that day. In effect, we are just removing the spatial variation from the temporal variation for that particular slit position. Only the average spatial variations are removed, as one sees from examination of the remaining scatter around the equatorial line strength on any particular day.

Table II summarizes the spatial means for each time period. Table III is a complete tabulation of the data for this paper, including the values for the unnormalized relative

CO₂ line strength, R_{CO_2} and the $R_{\text{CO}_2}(\odot)$ normalized to the solar line, and the $R_{\text{CO}_2}(\text{EQ})$ normalized by the procedure outlined in the previous paragraph to remove the spatial asymmetries.

During the September 1972 period of time, the other slit positions seem to follow fairly closely the variation in relative CO₂ line strength observed over the equatorial regions. There is an asymmetry between North and South regions with the northern CO₂ line strengths being 3% lower than the southern region when averaged over the observational period. This asymmetry is marginal considering the ± 2 to 3% errors in the spatial means, but the magnitude and sense of the asymmetry is in agreement with that found by Young, et al. (1974) for the Table Mountain data during the same time period.

Figure 2 shows the standard curve as taken from the Table Mountain observations (Young, et al., 1974) during the same time period and observations made at McDonald for the equatorial region. The McDonald observations have been normalized to the equatorial region, as indicated on the inset. Although we seem to observe a larger variation in line strength between slit positions on Venus than Table Mountain measurements indicate and their observations have been normalized to a standard position which was a North-South slit position in the center of the disk, there is a general agreement between the maxima and the minima. Their

equatorial data are indicated by filled circles and these show that on the days when the McDonald equatorial data do not agree very well with their standard curve. Likewise, the Table Mountain equatorial data do not agree either with their standard curve on those particular dates. This disagreement between standard curve variation and a particular slit position is indicative of the fact that we are not observing a uniform periodic fluctuation in the planet-wide CO_2 abundance, but we are observing "weather" on Venus. Sometimes we find that for a particular position on the planet the relative CO_2 line strength will behave in a predictable fashion for two or three days and then unpredictably for a few days.

For the September 1972 period we also observed daily the $7820\text{\AA}$ CO_2 band with the coude scanner of the 272cm telescope and the three CO_2 bands at 1μ with the coude spectrograph of the 208cm telescope. The $7820\text{\AA}$ band closely follows that described in Figure 1 but does not add any additional days to the set of observations. The $7820\text{\AA}$ data will be used with the bands at 1μ to define a final McDonald curve when the lengthy and time consuming analysis of 176 photographic spectra is completed.

August 1973. Figure 3 shows observations which were made during August of 1973. During a period of 19 days we made observations on 15 days and, much to our surprise, obtained a curve which seems to have a maximum every six

days rather than the four days previously observed. The data have been processed as before although we cut down the scan range and used only the P8-P32 CO₂ lines.

A six-day periodicity is noted in either the maxima or minima of the equatorial curve. It was unfortunate that poor terrestrial weather broke up the coverage between JD2441910 and -1916. The nature of the oscillation seems to be a burst to a maximum then a slow decay for five days followed by another burst. A set of observations beyond the last day would have been informative since the next maximum should have occurred on the day after the last set of observations. The line strengths for N/3 and S/3 slit positions followed that of the equatorial position closely, but the N2/3 and S2/3 regions did not vary as much or in phase with the equatorial position. The North-South asymmetry was negligible.

To test the possibility that some of this effect is caused by our spectrograph or by terrestrial weather rather than the Venus atmosphere, we have analyzed the variation of individual intensity obtained for solar lines during the same periods of time. No significant correlation is present between the observed CO₂ variations and variations of the solar lines themselves. The correlation coefficient was 0.005 for 69 scans during the August 1973 run. Since we have only two or three solar lines to measure in our regions which are not contaminated with CO₂ lines, the statistics

are not as accurate as one would wish, but we believe that the reported CO_2 variations are accurate to within a 2 to 3% error bar on a particular relative intensity. As a check on our reduction procedure, the data were processed without the solar line normalization. The results appear in Figure 3b. The shape and variations are similar except that the third maxima is diminished. Since solar normalization will remove any undetected changes in the coude system, such as a resolution or focus change, the remainder of the data were reduced with a solar line normalization.

October 1973. In October 1973 we obtained, over a short period of time, a set of relative CO_2 line strengths presented in Figure 4 which did not seem to have any definite periodic variation, although all slit positions seem to vary in accord with other slit positions observed on a particular day, except the equatorial on the last day. The problem here is that we simply do not have a long enough time base to determine any periodicity. It is possible, looking at the minima in the curves, that the atmosphere is changing with a two-day period. But this conclusion is very uncertain based on the small number of days observed. We do note the small terminator limb asymmetry (Limb 3% > Term) in this particular set of data. This asymmetry is exactly opposite to that observed during the next period of time, in December 1973. Again in this set of data, the southern half of the disk has systematically a 4% greater CO_2 line

strength than the northern half.

December 1973. In December 1973 we observed only during a five day period with four days of observations (Figure 5), but there is one definite conclusion we can draw: a four-day periodicity will not fit these data at all. Any periodic variation has to be greater than four days, probably on the order of five or six, although we did not observe more than one maximum or minimum in a particular slit position. Again we observe a systematic North-South variation (South 5% > North) with the South two-thirds slit position having an 8% greater CO₂ line strength than the North two-thirds position. The terminator has a 3% greater CO₂ line strength than the limb, which agrees with the terminator-limb asymmetry noted by Young, et al. (1974) in their September 1972 data.

As a check on the procedure of normalization to the single solar line, the December data are presented in Figure 5b. The shape and magnitude of the variations are very similar for these 23 relative CO₂ line strengths which had a correlation coefficient of 0.133 with the relative solar line strength. The remainder of the data presented, September 1972, October 1973, and January-February 1974 had a slight positive correlation with the strength of the solar line. Since the effect of normalizing to the solar line is to remove any positive correlation, all of the other data have been normalized to the solar line.

June 1972. After inferior conjunction in June 1972, we observed the CO₂ abundance variations tabulated in Table IV (Barker and Schorn, 1973 and Schorn and Barker, 1973). The slit positions for the inferior conjunction data refer to chords centered on the visible crescent at several latitudes with respect to the intensity equator. For example, CCEQ refers to the center of the crescent at an intensity latitude of 0°.

The total abundance ($\eta\omega$) was determined by methods similar to those described by Young (1972). The observed equivalent widths fit an assumption of the slope of the curve of growth ($b = 1$) much better than assuming $b = 0.5$. Also, the rotational temperatures had much smaller scatter and a more meaningful range of values.

Here as before, except that we are using relative CO₂ abundances instead of relative line strengths, we have removed the average spatial asymmetry observed during the June period. Then we have normalized to the mean equatorial position for the entire run, showing the remaining relative variations of the other portions of the crescent with respect to the equatorial portion of the crescent. Note here that since the vertical scale in Figure 6 has been compressed by a factor of five, we now have a variation on the order of 60% during a six or seven day period rather than 20% that we have been observing at smaller phase angles. The June 1972 data do not show any particular periodicity over the nine days sampled. During this period of time we find individual northern regions

to have up to 100% more CO_2 than the individual southern regions of the crescent.

January-February 1974. In January and February of 1974 we have been able to observe Venus before and after inferior conjunction, which occurred on the twenty-third of January. Before conjunction we observed on seven of eight days starting at 158° phase angle and ending at a phase angle of 170° . After conjunction, we began observations at a phase angle of 167° and continued through a phase angle of 148° , observing 10 of 12 days during that period of time. We have found the same large scale variations in the

CO₂ abundance between different portions of the illuminated crescent as we had found in June 1972. In particular, the South 45° latitude regions showed systematically twice the CO₂ abundance as that observed over the Northern 22° latitude region. Again the vertical scale has been compressed by a factor of five over that of the smaller phase angle observations so that we are really observing percentage changes of 25 to 100% between individual locations on the disk. In the upper half of the graph the data has been treated in the same manner as in the previous periodicity graphs: normalization to the equatorial regions and restriction to the days when the illuminated crescent remained fixed with respect to the atmosphere of Venus. Over the entire period of time the relative line strength for the North 22° slit position was systematically 2 to 7% less than the equatorial slit position and the South 45° slit positions were roughly 50 to 70% greater in CO₂ line strength than the equatorial region. In the lower half of the graph we have merely shown the mean of all observations of the relative line intensities on a particular day. This includes data taken when the crescent began to rotate through the south with respect to Venus' atmosphere. These days occurred on the last three days of observations before inferior conjunction and the first three days of observations after inferior conjunction. On the two days (JD2442076 and -2085) our only observations were made at the CCEQ and CCS22 positions with all other days containing three to

five slit positions. Any periodicity in the post-conjunction data must have at least a nine day period when we look at the entire mean curve. This greater than nine-day period is also suggested in the normalized relative CO₂ line strength in the upper half of the graph.

III. DISCUSSION

We have observed at seven different times in the Venus year, in addition to "weather" changes, various semi-periodicities (four, six and possibly nine days) were found in the CO₂ line strength (Table I). All the periodic variations indicated an increasing asymmetry between the Northern and Southern hemispheres with approach to inferior conjunction or with increasing phase angle. The magnitude of the asymmetry ranged from about 0% at $i = 49^\circ$ to 60% differences between Northern and Southern slit positions near inferior conjunction ($i = 150^\circ$). For the past Venus apparition, the southern half of the illuminated disk has been systematically higher in its CO₂ content. The spatial asymmetries are summarized in Table II.

Both observational periods near inferior conjunction, June 1972 and January-February 1974, have strong asymmetries (2x) between the Northern and Southern portions of the crescent, but the sense of the asymmetry is reversed in the 1974 ($S > N$) from that observed in 1972 ($N > S$). A possible conclusion could be that we are observing long term changes

(greater than a year) in the CO_2 line strength.

The real reason for the asymmetry becomes apparent when the slit positions of the various scans are referred to the planet or atmospheric equator and not the intensity equator. In both cases at inferior conjunction, the slit positions which had the factor of two greater CO_2 abundance or line strength were over the polar latitudes of the atmosphere. Similarly, the lower abundance slit positions (CCS45 in 1972 and CCN22 in 1974) were over the equatorial latitudes of the atmosphere. The polar versus equatorial asymmetry in CO_2 abundance was noted earlier by Moroz (1971). Although his reduction techniques were questioned by Hunt and Schorn (1971), he did detect a factor of three in the CO_2 equivalent widths of the 1.58 and 1.61μ bands between the equatorial and polar latitudes near inferior conjunction in 1969. The viewing geometry of the crescent on 17.0 January 1974 was similar to that in 1969 with both observations having the same magnitude and sense of the CO_2 abundance asymmetry. Figure 8 shows the crescent geometry for 17.0 January 1974 which was representative of the configuration during the 1974 inferior conjunction. The CCN45 position refers to $\phi = +2^\circ$ and the CCS45 position refers to $\phi = -88^\circ$. The increasing North-South asymmetry noted during 1973 also fits into this picture since the positions for August ($N \sim S$) were centered on the equator. No asymmetry was to be expected. By December 1973 the North two-thirds slit was sampling equatorial regions

and the South two-thirds slit was over the south polar region hence the (S 8% > N) asymmetry (See Figure 5).

High resolution line profiles of the P16 line in the $8689\text{\AA}$ CO_2 band on JD 2442079 were taken with the coude scanner in the echelle grating mode. The central control depth of the P16 CO_2 increased by 60% between the CCS45 ($\phi = -64^\circ$) and CCEQ ($\phi = -19^\circ$) positions on the crescent. Also, the wings of the P16 CO_2 line did not change at all. The phase angle was 157° consequently single scattering dominated over multiple scattering processes. With this additional observational evidence, we conclude that the level of line formation must be lower over polar latitudes than over equatorial regions, to give the observed increase in the polar CO_2 line strength or abundance.

Amplitude of the periodicity increased from relatively small values at smaller phase angles on the order of 15 to 25% at 110° phase angle, to greater than 50% for observations at inferior conjunction. The amplitude of the variations of CO_2 position on the crescent is much greater near inferior conjunction; either because (1) we are sampling a smaller area on the planet hence with less averaging effect of large, real differences in atmospheric structure, or (2) the upper atmospheric CO_2 abundance which is observed near inferior conjunction primarily results from single scattering which is quite sensitive to the cloud top position because most of the absorption occurs above the cloud tops and not

in the clouds as in the case for multiple scattering. The daily CO_2 line strength changes must also be due to changes in the vertical level of line formation or height of the tops of the lower cloud deck.

Definitely, the CO_2 abundance changes in several ways with location on the planet, phase angle, and time of the observation.

During most of these observational runs to measure the CO_2 line strength, we have been able to observe the H_2O abundance over the same locations at which we measured the relative CO_2 line strengths. In the data through February of 1974, we see a complete lack of correlation, positive or negative, between CO_2 line strength and H_2O abundance. Details of this H_2O - CO_2 correlation analysis will be presented elsewhere (Barker, 1974b).

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APPENDIX A

The average residual line intensity (R_{CO_2}) is presented in Table II. To convert this observed quantity into an equivalent width measurement requires the following information for each data set: (1) The particular CO_2 lines included in the averaging process; (2) The width of the base of the triangular line profile since we are observing only the instrumental profile at a resolution of 0.3 or 0.2Å; (3) An assumption about the slope of the curve of growth for this band, usually $b = 0.5$ is satisfactory except near inferior conjunction. Table V contains the necessary information to convert the CO_2 residual intensities (R_{CO_2}) into equivalent widths (or relative amounts of CO_2) for each scan of data presented in Table III. The calculation of absolute amounts of CO_2 requires the assumption of a model atmosphere (pressure, temperature, scattering functions, and al distribution, etc.) which is beyond the scope of this paper.

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FIGURE CAPTIONS

- FIG. 1. Relative CO_2 line strengths for September 1972 as a function of date with the spatial asymmetries removed. Symbols identified on the inset. The position of equator of Venus is noted on inset by dashed line.
- FIG. 2. Comparison of the standard region of relative CO_2 line strengths determined by Young, et al. (1974) at Table Mountain with the McDonald equatorial region curve. The position of the equator of Venus is noted on inset by dashed line.
- FIG. 3a. Relative CO_2 line strengths for August 1973 as a function of date with the spatial asymmetries removed. Symbols identified on the inset. The position of equator of Venus is noted on inset by dashed line.
- FIG. 3b. Same data as FIG. 3a but data not normalized to solar line.
- FIG. 4. Relative CO_2 line strengths for October 1973 as a function of date with the spatial asymmetries removed. Symbols identified on the inset. The position of equator of Venus is noted on inset by dashed line.

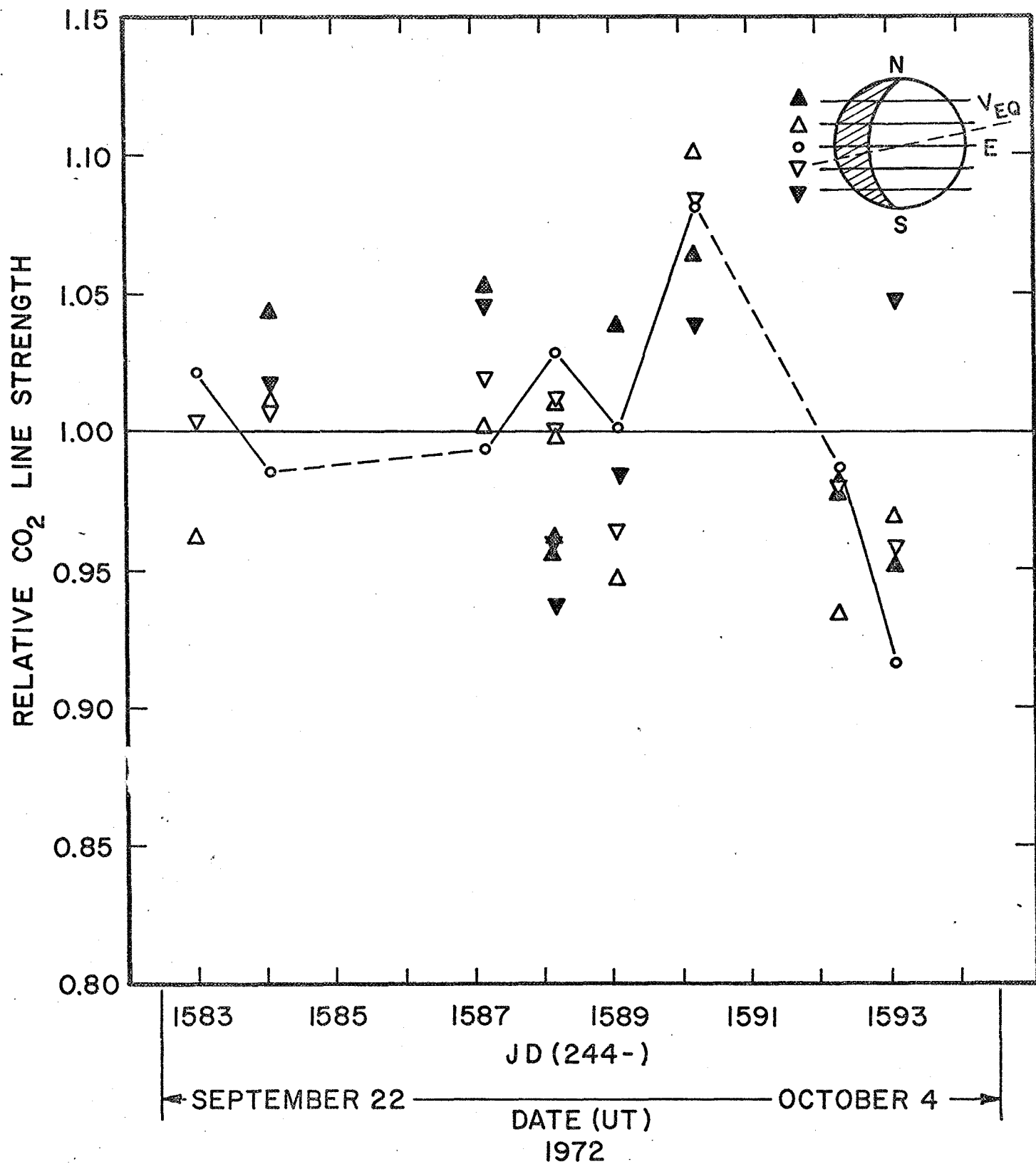
FIG. 5a. Relative CO₂ line strengths for December 1973 as a function of date with the spatial asymmetries removed. Symbols identified on the inset. The position of equator of Venus is noted on inset by dashed line.

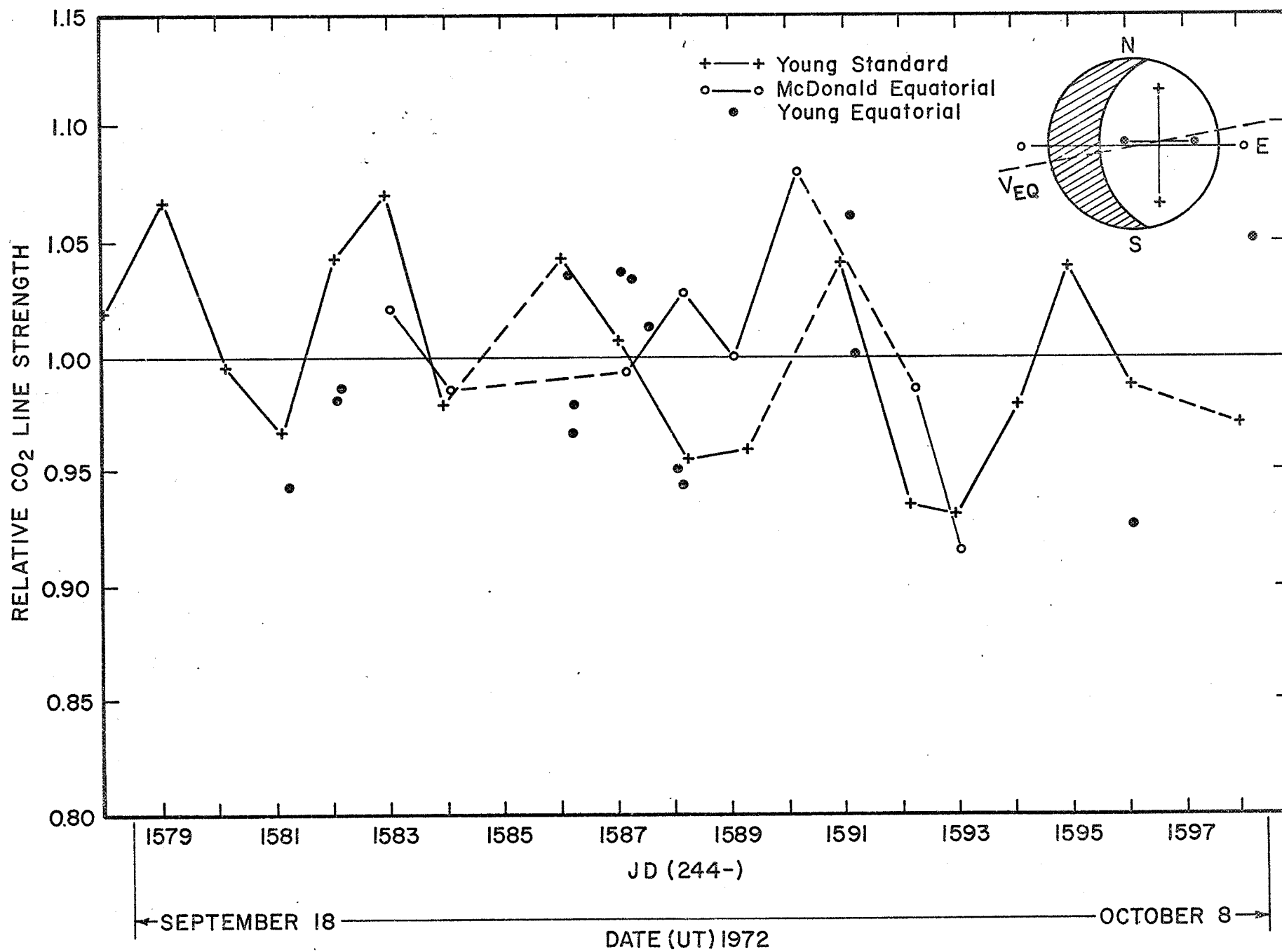
FIG. 5b. Same data as FIG. 5a but data not normalized to solar line.

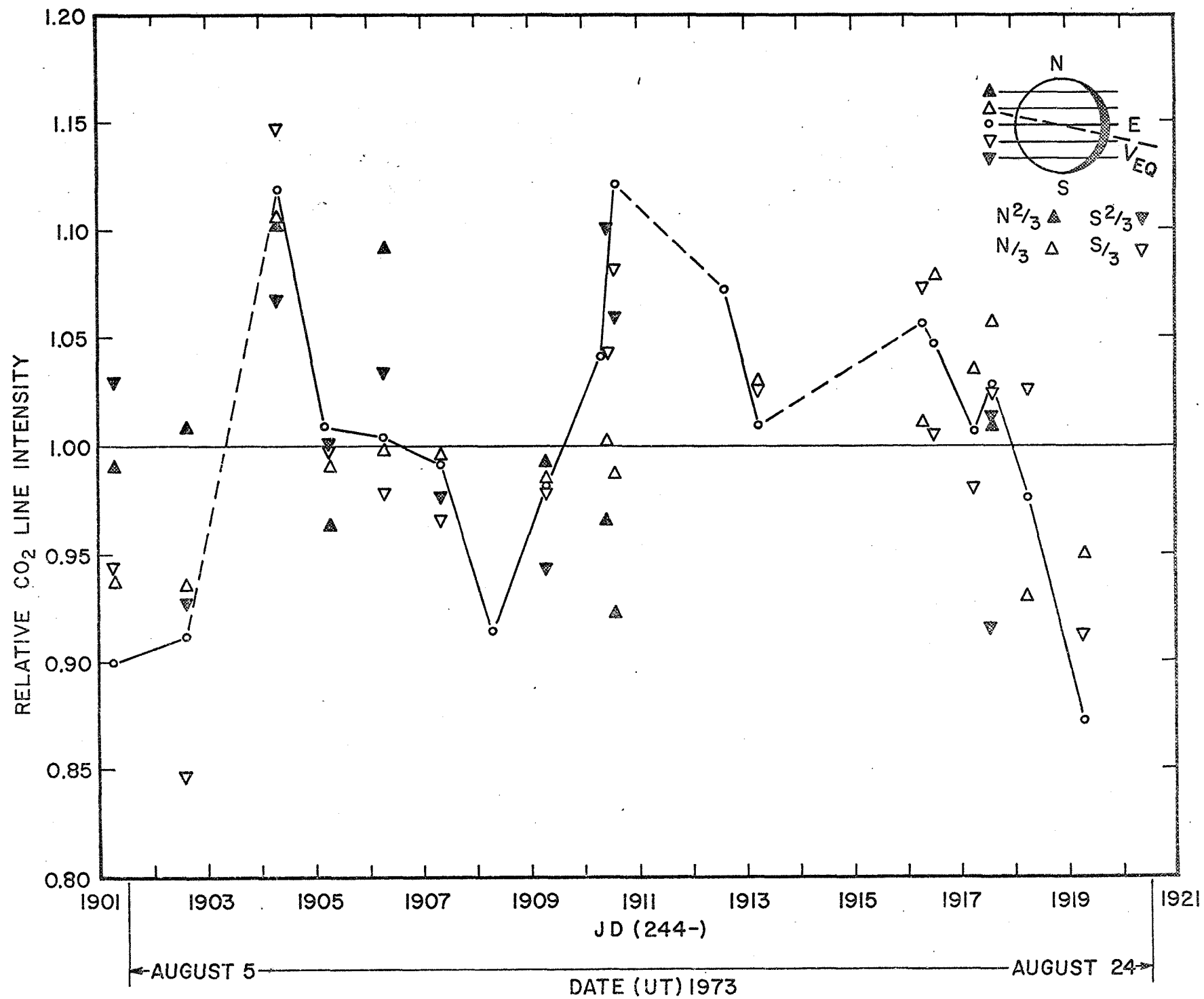
FIG. 6. 1972 inferior conjunction relative CO₂ line strengths as a function of date with the spatial asymmetries removed. Symbols identified on the inset. The position of equator of Venus is noted on inset by dashed line.

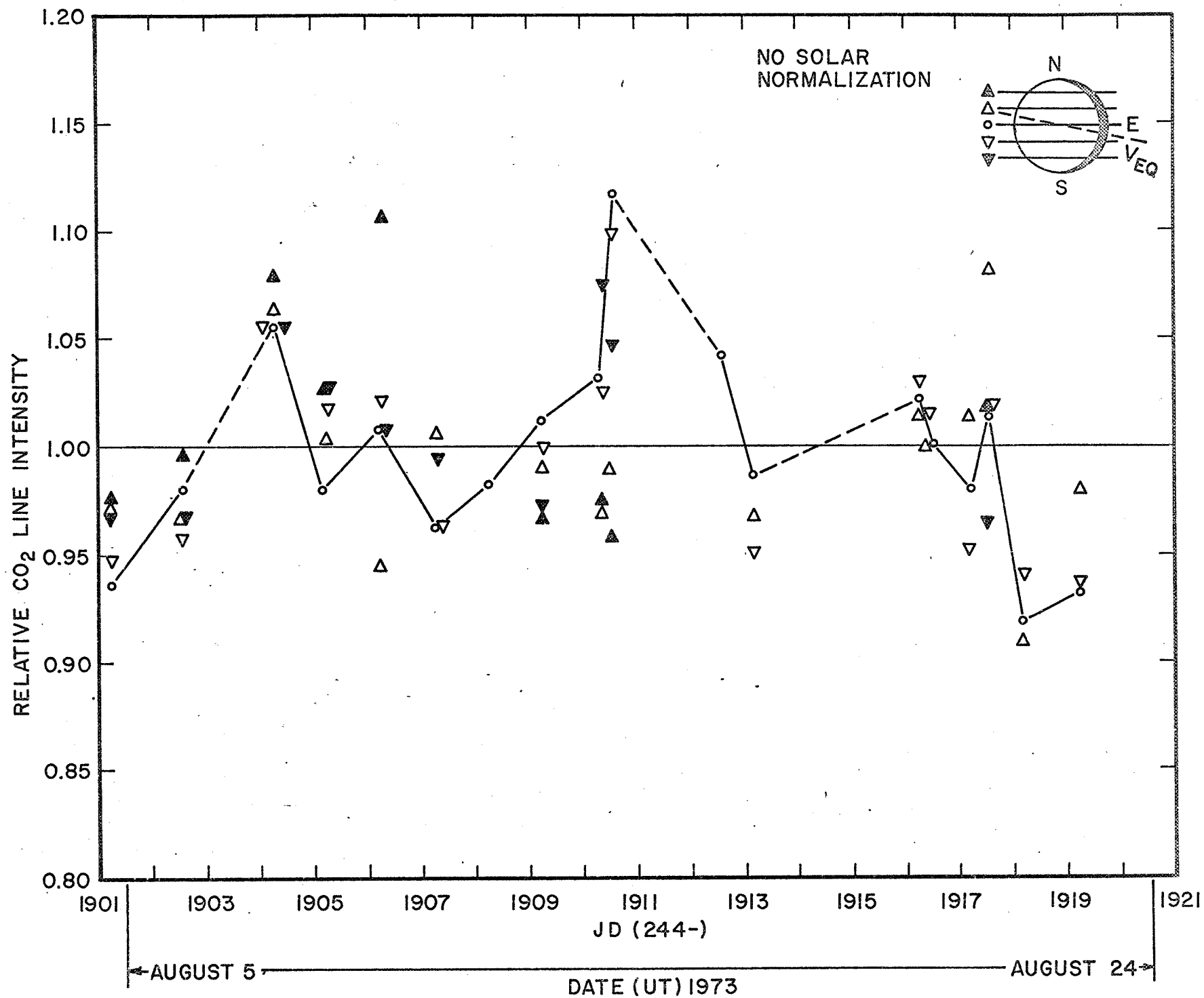
FIG. 7. 1974 inferior conjunction relative CO₂ line strengths as a function of date with the spatial asymmetries removed. Symbols identified on the inset. The position of equator of Venus is noted on inset by dashed line. Upper portion of figure restricted to days when crescent remained fixed with respect to the Venus atmosphere. The lower portion has mean of all locations observed on a single day.

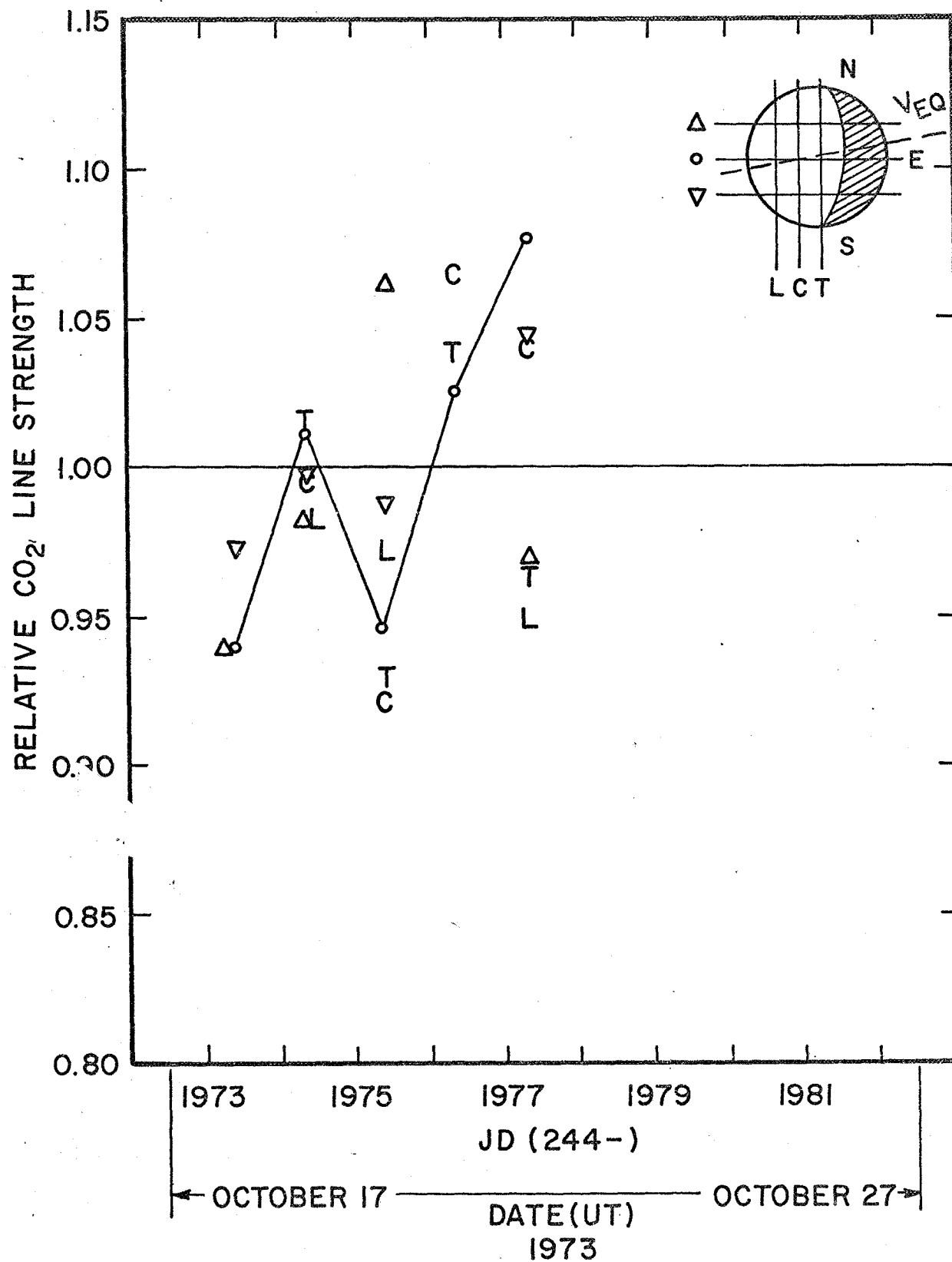
FIG. 8. Geometry of Venus crescent near 1974 inferior conjunction (17.0 January 1974). The planetary latitude is given for each slit position.

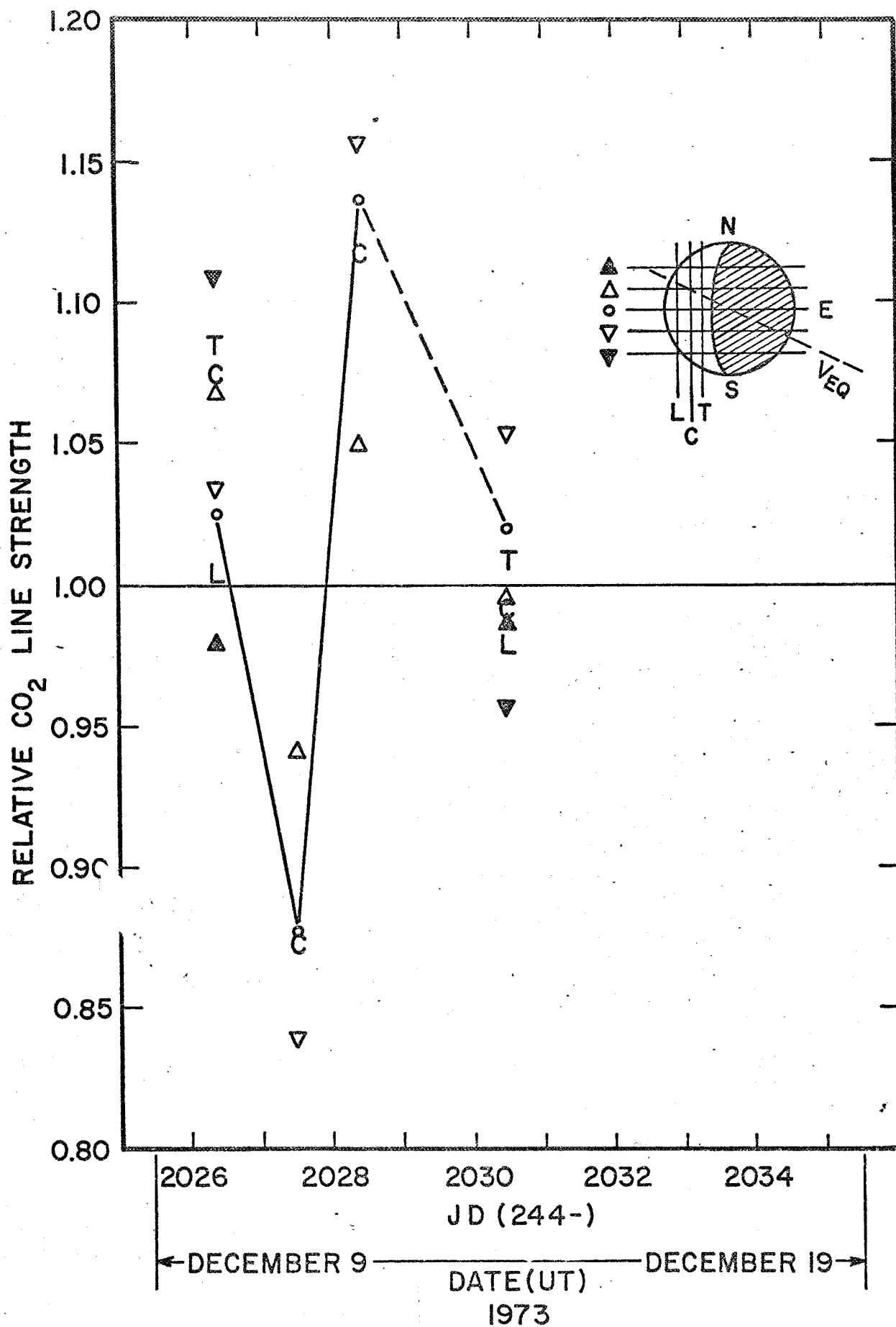


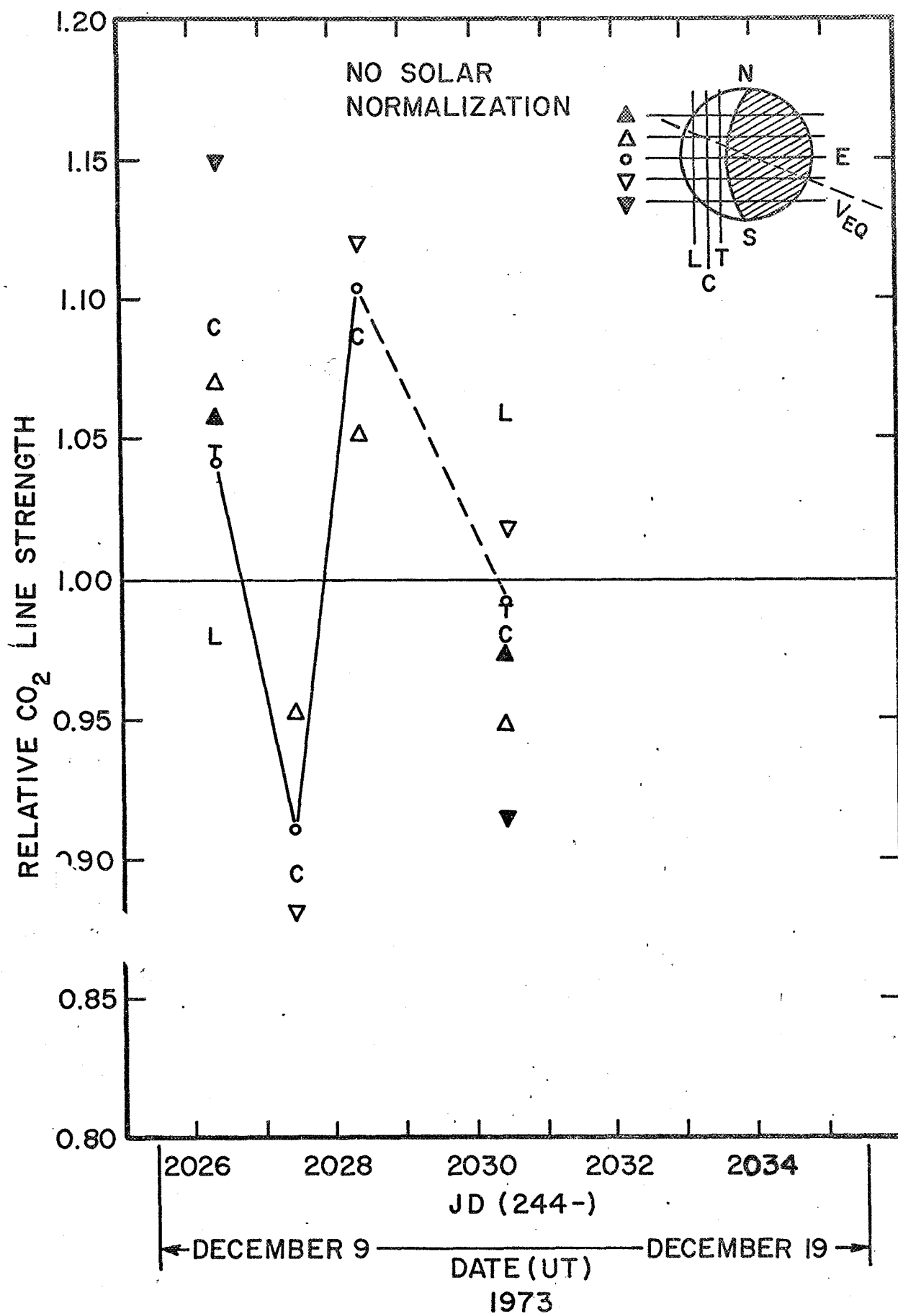


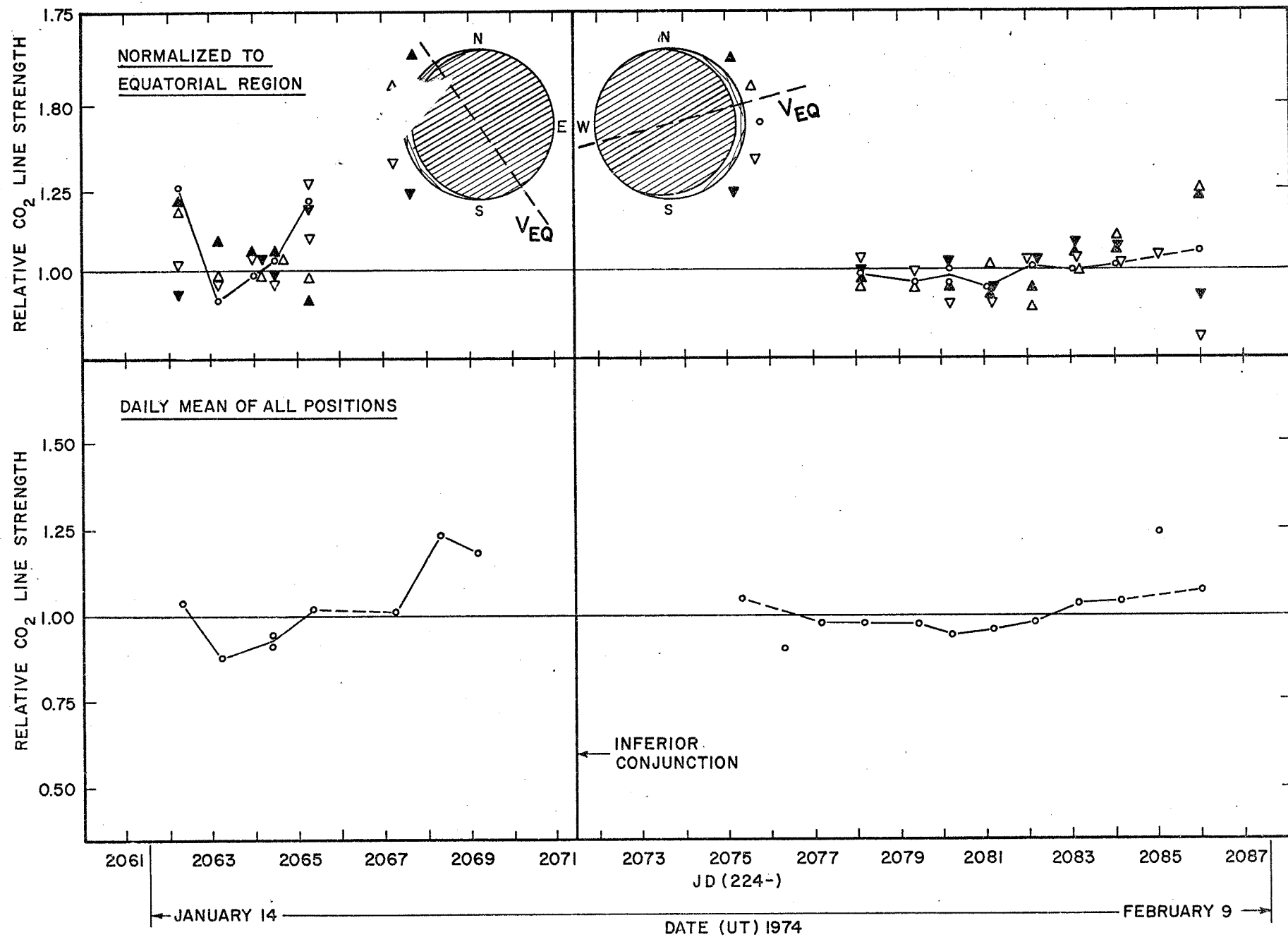


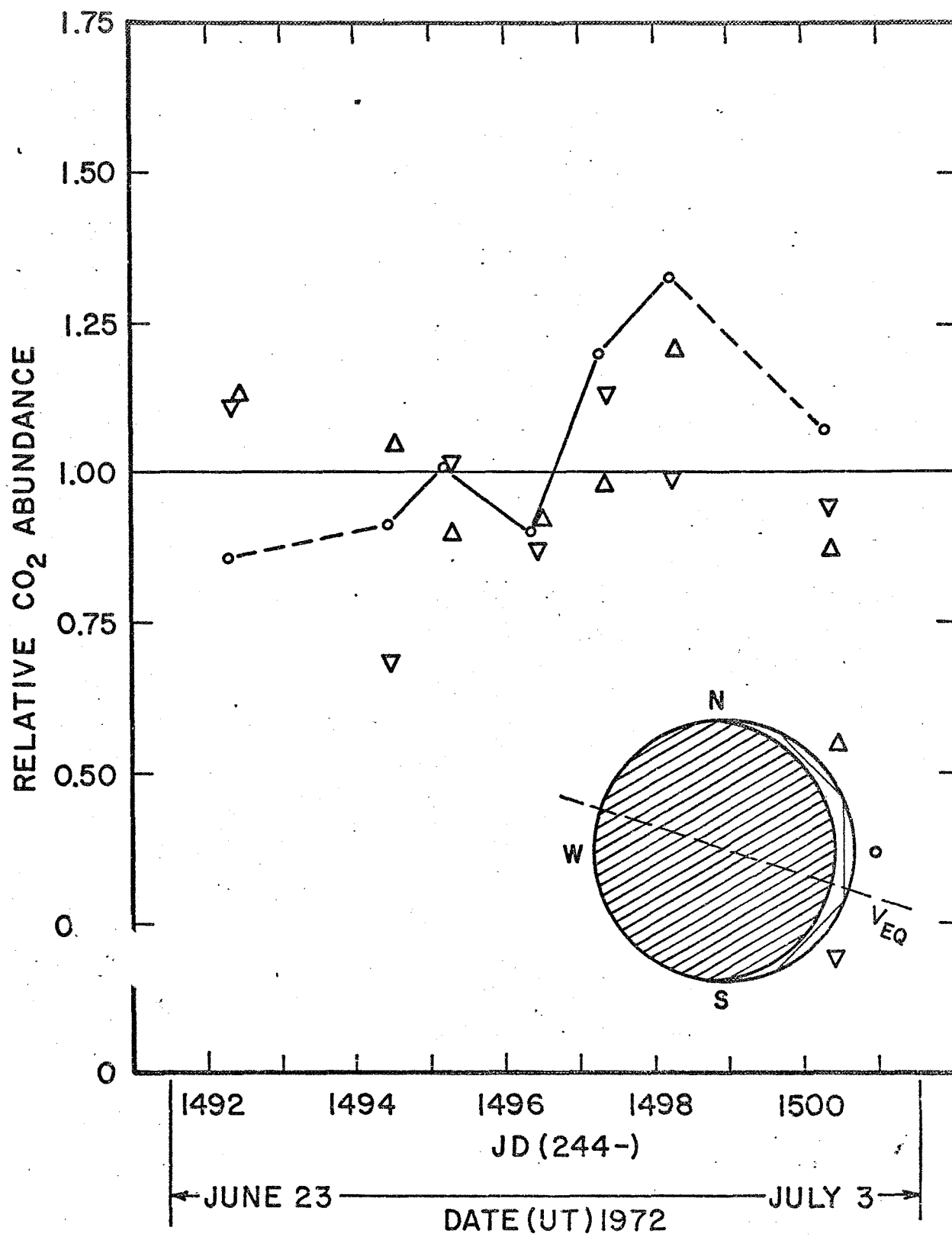




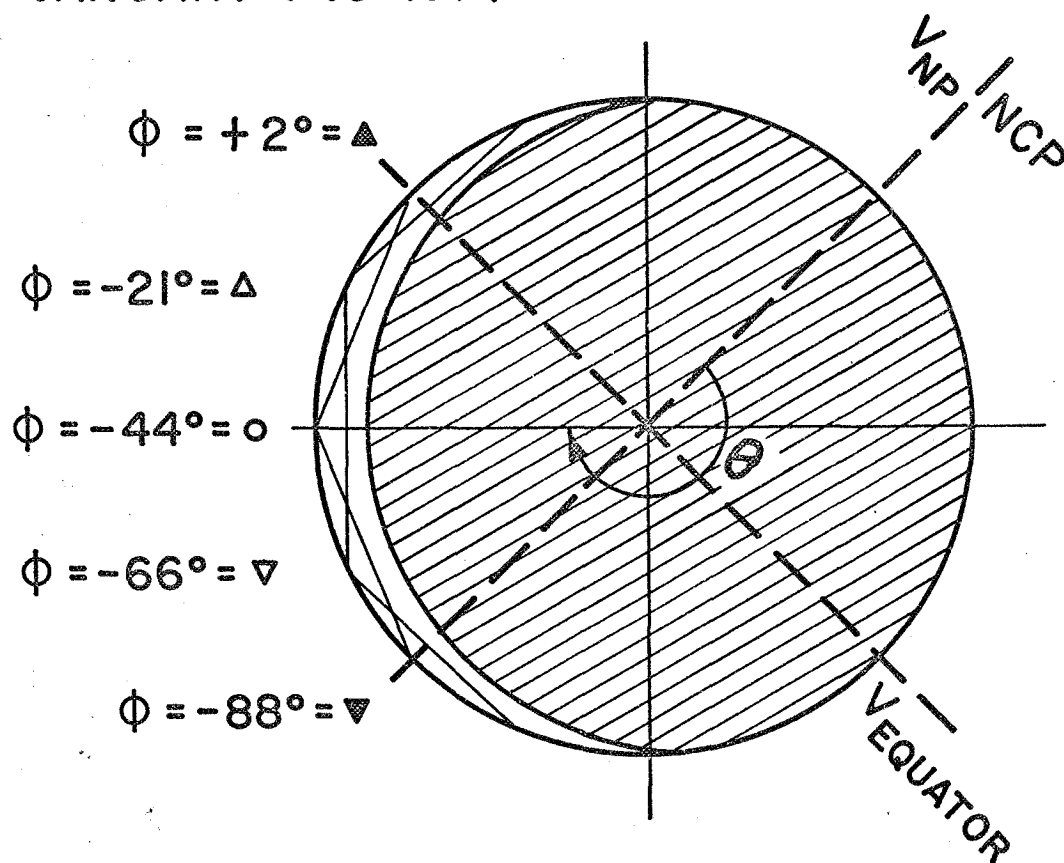








SLIT POSITIONS
IN TERMS
VENUS LATITUDE ϕ
JANUARY 17.0 1974



θ = P.A. OF BRIGHT POINT OF CRESCENT

Table I
Summary of Venus CO₂ Line Strength Observations

Time	Coverage	Period	Amplitude		Phase Angle	Comments
			Raw	Normalized		
Sept 1972	9 of 12 days	~4 days	39%	20%	75° to 70°	all positions behave similarly; EQ odd on 2 days; S(3%>)N
Aug 1973	15 of 19 days	~6 days	30%	28%	47° to 54°	3 definite peaks; no variation in N2/3 and S2/3; S(≈)N
Oct 1973	5 of 5 days	?	22%	18%	76° to 79°	sample too short; 2 day period?; EQ funny on last day; S(4%>)N; Limb(3%>)Term
Dec 1973	4 of 5 days	>4 days	32%	30%	109° to 113°	all positions behave similarly; S(5%>)N; Term(3%>)Limb
<u>Inferior Conjunction Data</u>						
June 1972	7 of 9 days	6(?) days	100%	60%	167° to 150°	N(2x stronger than)EQ or S
Jan 1974	7 of 8 days	?	75%	50%	158° to 170°	sample too short; S45(1.7x>)N22
Feb 1974	10 of 12 days	>9 days	70%	60%	165° to 148°	S45(1.6x>)N22

Table II

Spatial Means with respect to Equatorial Region of Day

Date	N2/3	N/3	S/3	S2/3	Limb	CD	Term	N/2	S/2
Sept 1972	0.976 ±0.002	0.979 ±0.002	1.007 ±0.001	1.008 ±0.004	--	--	--	0.974 ±0.002	1.013 ±0.001
Aug 1973	0.920 ±0.003	0.982 ±0.002	0.984 ±0.001	0.916 ±0.002	--	--	--	--	--
Oct 1973	--	--	--	--	0.976 ±0.001	0.930 ±0.001	0.947 ±0.001	0.930 ±0.004	0.967 ±0.002
Dec 1973	0.950 ±0.002	0.978 ±0.002	0.982 ±0.002	1.034 ±0.002	0.972 ±0.001	0.968 ±0.001	1.000 ±0.002	--	--

Inferior Conjunction Data

Date	NT (7820)	NT (8700)	ST (7820)	ST (8700)	N45	N22	S22	S45
June 1972	1.600 ±0.248	1.310 ±0.577	1.141 ±0.248	1.091 ±0.463	--	--	--	--
Jan 1974	--	--	--	--	1.009 ±0.001	0.977 ±0.001	1.105 ±0.001	1.693 ±0.003
Feb 1974	--	--	--	--	0.869 ±0.001	0.925 ±0.001	1.261 ±0.002	1.503 ±0.001

Table III
Relative CO₂ Line Strengths

Scan No.	JD (244-)	R _{CO₂}	R _{CO₂} (☉)	R _{CO₂} (EQ)
September 1972				
2210 EQ	1583.006	0.118	0.636	1.021
2211 N/2	1583.015	0.115	0.584	0.962
2212 S/2	1583.023	0.121	0.634	1.004
2219 EQ	1584.063	0.116	0.614	0.986
2220 N3/4	1584.067	0.123	0.651	1.045
2221 N/2	1584.072	0.116	0.631	1.040
2222 N/4	1584.075	0.117	0.610	0.979
2223 S/4	1584.078	0.118	0.632	1.014
2224 S/2	1584.083	0.123	0.633	1.004
2225 S3/4	1584.088	0.128	0.644	1.035
2315 EQ	1587.152	0.124	0.619	0.994
2316 N2/3	1587.152	0.115	0.640	1.053
2317 N/3	1587.152	0.112	0.611	1.002
2318 S/3	1587.152	0.117	0.640	1.020
2319 S2/3	1587.152	0.120	0.657	1.046
2422 N2/3	1588.169	0.107	0.585	0.999
2423 N/3	1588.172	0.112	0.609	0.962
2424 EQ	1588.177	0.117	0.656	1.053
2425 S/3	1588.180	0.116	0.628	1.002
2426 S2/3	1588.184	0.112	0.602	0.959
2427 N2/3	1588.189	0.107	0.581	0.956
2428 N/3	1588.194	0.110	0.616	1.010
2429 EQ	1588.197	0.112	0.624	1.003
2430 S/3	1588.200	0.114	0.635	1.012
2431 S2/3	1588.204	0.110	0.589	0.938
2506 N2/3	1589.060	0.110	0.632	1.039
2507 N/3	1589.063	0.102	0.578	0.947
2508 EQ	1589.070	0.109	0.623	1.001
2509 S/3	1589.083	0.110	0.605	0.965
2510 S2/3	1589.099	0.112	0.619	0.986
2614 N2/3	1592.274	0.111	0.596	1.101
2615 N/3	1592.274	0.113	0.570	1.064
2616 EQ	1592.274	0.110	0.615	1.081
2617 S/3	1592.274	0.109	0.615	1.084
2618 S2/3	1592.274	0.112	0.614	1.040

Table III (Cont.)
Relative CO₂ Line Strengths

Scan No.	JD (244-)	R _{CO₂}	R _{CO₂} (°)	R _{CO₂} (EQ)
2544 N2/3	1590.178	0.121	0.647	0.980
2545 N/3	1590.181	0.120	0.672	0.934
2546 EQ	1590.184	0.124	0.674	0.987
2547 S/3	1590.191	0.122	0.680	0.981
2548 S2/3	1590.191	0.118	0.653	0.978
2681 N2/3	1593.085	0.108	0.579	1.048
2682 N/3	1593.088	0.106	0.591	0.952
2683 EQ	1593.090	0.109	0.570	0.969
2684 S/3	1593.093	0.110	0.601	0.916
2685 S2/3	1593.096	0.113	0.658	0.959
August 1973				
4115 EQ	1901.230	0.151	0.820	0.898
4116 N2/3	1901.230	0.144	0.831	0.990
4117 N/3	1901.230	0.154	0.839	0.937
4118 S2/3	1901.230	0.146	0.860	1.030
4119 S/3	1901.230	0.150	0.847	0.044
4193 EQ	1902.551	0.158	0.832	0.911
4194 N2/3	1902.551	0.147	0.846	1.007
4195 N/3	1902.551	0.153	0.838	0.935
4196 S/3	1902.551	0.152	0.760	0.847
4197 S2/3	1902.551	0.146	0.774	0.927
4239 EQ	1904.240	0.170	1.020	1.118
4240 N2/3	1904.240	0.160	0.926	1.102
4241 N/3	1904.240	0.168	0.992	1.106
4242 S/3	1904.240	0.167	1.029	1.147
4243 S2/3	1904.240	0.159	0.893	1.069
4319 EQM	1905.145	0.158	0.921	1.009
4322 S2/3	1905.240	0.155	0.837	1.001
4323 S/3	1905.240	0.162	0.897	0.999
4324 N/3	1905.240	0.159	0.887	0.990
4325 N2/3	1905.240	0.152	0.809	0.963
4351 EQ	1906.220	0.163	0.916	1.004
4362 N/3	1906.240	0.149	0.895	0.999
4363 N2/3	1906.240	0.164	0.917	1.092
4364 S/3	1906.250	0.162	0.879	0.979
4365 S2/3	1906.250	0.152	0.865	1.035
4394 EQ	1907.300	0.156	0.905	0.992
4395 N/3	1907.300	0.159	0.892	0.995
4398 S/3	1907.300	0.153	0.867	0.966
4399 S2/3	1907.300	0.150	0.817	0.978

Table III (Cont.)
Relative CO₂ Line Strengths

Scan No.	JD (244-)	R _{CO₂}	R _{CO₂} (☉)	R _{CO₂} (EQ)
4428 EQ	1908.270	0.159	0.834	0.914
4452 EQ	1909.270	0.164	0.894	0.980
4453 N/3	1909.270	0.157	0.882	0.985
4454 S/3	1909.270	0.159	0.878	0.979
4455 S2/3	1909.270	0.147	0.788	0.943
4456 N2/3	1909.270	0.143	0.833	0.993
4486 EQM	1910.300	0.167	0.950	1.041
4488 N/3	1910.380	0.153	0.898	1.002
4489 S/3	1910.380	0.163	0.937	1.044
4490 S2/3	1910.380	0.162	0.920	1.101
4491 N2/3	1910.380	0.144	0.811	0.965
4506 EQ	1910.530	0.180	1.023	1.121
4507 S/3	1910.530	0.174	0.971	1.082
4508 N/3	1910.530	0.157	0.885	0.987
4510 N2/3	1910.545	0.142	0.775	0.923
4511 S2/3	1910.545	0.158	0.886	1.060
4518 EQ	1912.556	0.190	0.979	1.073
4527 EQ	1913.200	0.159	0.921	1.009
4528 S/3	1913.200	0.151	0.921	1.026
4529 N/3	1913.200	0.153	0.923	1.029
4548 EQ	1916.280	0.165	0.964	1.057
4549 S/3	1916.280	0.163	0.963	1.073
4550 N/3	1916.280	0.160	0.907	1.012
4551 EQ	1916.490	0.162	0.956	1.047
4552 S/3	1916.501	0.161	0.902	1.005
4553 N/3	1916.501	0.158	0.967	1.078
4574 EQ	1917.230	0.158	0.918	1.007
4575 S/3	1917.230	0.151	0.880	0.980
4576 N/3	1917.230	0.160	0.928	1.035
4607 EQ	1917.558	0.164	0.938	1.028
4608 S/3	1917.558	0.162	0.919	1.024
4609 N/3	1917.558	0.171	0.948	1.057
4610 N2/3	1917.558	0.151	0.847	1.009
4611 S2/3	1917.558	0.145	0.765	0.916
4630 EQ	1918.230	0.148	0.890	0.976
4631 S/3	1918.230	0.149	0.921	1.026
4632 N/3	1918.230	0.144	0.833	0.930
4653 EQ	1919.280	0.151	0.795	0.872
4654 S/3	1919.280	0.149	0.818	0.912
4655 N/3	1919.280	0.155	0.851	0.949

Table III (Cont.)
Relative CO₂ Line Strengths

Scan No.	JD (244-)	R _{CO₂}	R _{CO₂} (☉)	R _{CO₂} (EQ)
October 1973				
4708 EQM	1973.359	0.162	0.801	0.939
4711 S/2	1973.395	0.149	0.802	0.972
4712 N/2	1973.395	0.145	0.745	0.939
4718 EQ	1974.329	0.165	0.862	1.011
4719 S/2	1974.337	0.158	0.823	0.988
4720 N/2	1974.342	0.149	0.779	0.983
4721 CD	1974.346	0.154	0.790	0.995
4722 WLIMB	1974.352	0.156	0.818	0.983
4723 TERM	1974.365	0.155	0.821	1.016
4726 EQ	1975.337	0.149	0.807	0.947
4727 S/2	1975.395	0.146	0.814	0.987
4728 N/2	1975.400	0.143	0.841	1.061
4729 CD	1975.408	0.144	0.731	0.922
4730 TERM	1975.411	0.140	0.751	0.930
4731 WLIMB	1975.415	0.150	0.810	0.973
4758 EQ	1976.319	0.163	0.874	1.025
4759 CD	1976.345	0.149	0.845	1.064
4761 TERM	1976.319	0.143	0.839	1.038
4794 EQ	1977.303	0.158	0.918	1.077
4795 S/2	1977.306	0.153	0.860	1.043
4796 N/2	1977.311	0.146	0.768	0.969
4797 TERM	1977.317	0.148	0.825	1.040
4798 TERM	1977.320	0.145	0.778	0.963
4799 WLIMB	1977.324	0.148	0.790	0.949
December 1973				
4914 EQ	2026.314	0.096	0.541	1.026
4915 N2/3	2026.314	0.095	0.491	0.979
4916 N/3	2026.314	0.099	0.551	1.069
4917 S/3	2026.314	0.098	0.536	1.034
4918 S2/3	2026.314	0.112	0.605	1.109
4919 CD	2026.314	0.098	0.549	1.075
4020 L/2	2026.314	0.094	0.515	1.005
4021 T/2	2026.314	0.097	0.573	1.087
4951 CD	2027.460	0.080	0.447	0.875
4952 EQ	2027.460	0.084	0.463	0.879
4953 S/3	2027.460	0.080	0.435	0.839
4954 N/3	2027.460	0.088	0.486	0.941

Table III (Cont.)
Relative CO₂ Line Strengths

Scan No.	JD (244-)	R _{CO₂}	R _{CO₂} (☉)	R _{CO₂} (EQ)
4972 CD	2028.369	0.097	0.571	1.118
4973 EQ	2028.369	0.102	0.600	1.137
4974 S/3	2029.369	0.102	0.599	1.157
4975 N/3	2028.369	0.097	0.542	1.050
5034 EQ	2030.456	0.091	0.538	1.020
5035 N/3	2030.456	0.087	0.514	0.996
5036 S/3	2030.456	0.093	0.546	1.054
5036 S2/3	2030.456	0.089	0.522	0.958
5038 N2/3	2030.456	0.088	0.495	0.987
5039 CD	2030.456	0.088	0.508	0.995
5040 T/2	2030.456	0.092	0.533	1.010
5041 L/2	2030.456	0.102	0.503	0.981

Pre-Inferior Conjunction 1974

5117 CCEQ	2062.290	0.041	0.210	1.241
5118 CCS22	2062.290	0.036	0.191	1.020
5119 CCS45	2062.290	0.051	0.268	0.936
5120 CCN22	2062.290	0.037	0.193	1.169
5121 CCN45	2062.290	0.039	0.206	1.204
5146 CCEQ	2063.210	0.030	0.154	0.912
5147 CCS22	2063.210	0.036	0.180	0.965
5148 CCS45	2063.210	0.055	0.287	1.001
5149 CCN22	2063.210	0.032	0.162	0.981
5150 CCN45	2063.210	0.037	0.185	1.086
5171 CCEQ	2064.390	0.032	0.168	0.992
5172 CCS22	2064.390	0.037	0.195	1.043
5173 CCS45	2064.390	0.057	0.298	1.042
5174 CCN22	2064.390	0.030	0.163	0.987
75 CCN45	2064.390	0.034	0.176	1.033
6 CCEQ	2064.390	0.033	0.174	1.026
5175 CCS22	2064.390	0.035	0.185	0.988
5178 CCS45	2064.390	0.054	0.284	0.992
5179 CCN22	2064.390	0.033	0.172	1.041
5180 CCN45	2064.390	0.035	0.179	1.051
5200 CCEQ	2065.320	0.040	0.203	1.201
5201 CCS22	2065.320	0.047	0.234	1.253
5202 CCS22	2065.320	0.040	0.204	1.092
5203 CCS45	2065.320	0.065	0.338	1.181
5204 CCN22	2065.320	0.030	0.161	0.976
5205 CCN45	2065.320	0.030	0.155	0.910

Table III (Cont.)
Relative CO₂ Line Strengths

Scan No.	JD (244-)	R _{CO₂}	R _{CO₂} (☉)	R _{CO₂} (EQ)
5229 CCEQ	2067.250	0.033	0.175	*
5230 CCS22	2067.250	0.057	0.295	*
5231 CCS45	2067.250	0.080	0.383	*
5233 CCN22	2067.250	0.034	0.160	*
5234 CCN45	2067.250	0.035	0.167	*
5250 CCEQ	2069.300	0.045	0.215	*
5251 CCS22	2068.300	0.066	0.314	*
5274 CCEQ	2069.170	0.056	0.271	*
5275 CCS22	2069.170	0.065	0.321	*
5276 CCS45	2069.170	0.065	0.314	*
5281 CCN22	2069.170	0.040	0.198	*
5282 CCN45	2069.170	0.037	0.189	*

Post-Inferior Conjunction 1974

5286	CCEQ	2075.290	0.045	0.230	*
5287	CCS22	2075.290	0.061	0.312	*
5292	CCS22	2076.280	0.061	0.300	*
5293	CCS45	2076.280	0.059	0.302	*
5294	CCN22	2076.280	0.037	0.202	*
5295	CCN45	2076.280	0.037	0.186	*
5296	EQM	2076.280	0.046	0.235	*
5303	CCEQ	2077.150	0.046	0.234	*
5304	CCS22	2077.150	0.065	0.329	*
5305	CCN22	2077.150	0.042	0.211	*
5322	CCEQ	2078.150	0.046	0.235	0.083
5323	CCN45	2078.150	0.039	0.200	0.963
5324	CCS45	2078.150	0.074	0.359	1.000
5325	CCS22	2078.150	0.062	0.312	1.038
5326	CCN22	2078.150	0.042	0.211	0.955
5349	CCEQ	2079.410	0.044	0.227	0.952
5350	CCS22	2079.410	0.057	0.299	0.995
5351	CCN22	2079.410	0.039	0.208	0.944
5357	CCEQ	2080.180	0.046	0.238	0.998
5358	CCS22	2080.180	0.050	0.270	0.899
5369	CCN22	2080.180	0.040	0.210	0.953
5370	CCN45	2080.180	0.038	0.196	0.947
5371	CCS45	2080.180	0.070	0.368	1.026

Table III (Cont.)
Relative CO₂ Line Strengths

Scan No.	JD (244-)	R _{CO₂}	R _{CO₂} (☉)	R _{CO₂} (EQ)
5393	CCEQ 2081.160	0.044	0.226	0.949
5394	CCS22 2081.160	0.054	0.274	0.911
5395	CCS45 2081.160	0.066	0.342	0.953
5396	CCN22 2081.160	0.044	0.223	1.012
5397	CCN45 2081.160	0.038	0.191	0.923
5427	CCEQ 2082.150	0.049	0.241	1.010
5428	CCS22 2082.150	0.063	0.308	1.025
5429	CCS45 2082.150	0.075	0.370	1.031
5430	CCN22 2082.150	0.040	0.197	0.892
5431	CCN45 2082.150	0.040	0.196	0.947
5453	CCEQ 2083.150	0.048	0.238	0.998
5454	CCS22 2083.150	0.063	0.313	1.040
5455	CCS45 2083.150	0.079	0.386	1.077
5456	CCN22 2083.150	0.043	0.220	0.999
5457	CCN45 2083.150	0.043	0.217	1.048
5481	CCEQ 2084.120	0.049	0.242	1.016
5482	CCS22 2084.120	0.062	0.308	1.023
5483	CCN22 2084.120	0.047	0.242	1.096
5484	CCN45 2084.120	0.045	0.220	1.063
5485	CCS45 2084.120	0.078	0.383	1.069
5508	CCS22 2085.050	0.062	0.314	1.044
5517	CCEQ 2086.050	0.052	0.251	1.054
5518	CCS22 2086.050	0.050	0.242	0.806
5519	CCN22 2086.050	0.053	0.271	1.228
5520	CCN45 2086.050	0.052	0.252	1.214
5521	CCS45 2086.050	0.067	0.334	0.930

*Crescent Rotation

Table IV
June 1972 CO₂ Abundances

Scan No.	Orient.	JD (244-)	$\eta\omega_{\text{CO}_2}$ km-atm	$\eta\omega_{\text{CO}_2}$ (EQ)
8689Å CO ₂ Band				
1723	CCN45	1492.394	0.203	1.240
1724	CCS45	1492.406	0.386	1.215
1725	CCEQ	1492.412	0.203	0.697
1753	CCN45	1495.270	0.359	0.941
1754	CCS45	1495.291	0.286	0.900
1755	CCEQ	1495.309	0.300	1.030
1768	CCN45	1496.465	0.282	0.739
1769	CCEQ	1496.472	0.270	0.927
1770	CCS45	1496.479	0.251	0.790
1787	CCEQ	1497.335	0.405	1.391
1788	CCS45	1497.344	0.293	0.922
1789	CCN45	1497.353	0.415	1.088
1791	CCN60	1497.404	0.576	1.978
1792	CCS60	1497.421	0.229	0.786
1809	CCN45	1500.334	0.321	0.841
1810	CCS45	1500.356	0.318	1.001
1811	CCEQ	1500.394	0.335	1.151
7820Å CO ₂ Band				
1718	CCEQ	1492.250	0.306	1.020
1719	CCS45	1492.285	0.349	1.019
1720	CCN45	1492.344	0.505	1.052
1731	CCEQ	1494.396	0.274	0.913
1732	CCS45	1494.422	0.235	0.686
1733	CCN45	1494.441	0.503	1.048
1734	CCEQ	1495.140	0.296	0.987
1750	CCS45	1495.192	0.390	1.139
1751	CCN45	1495.205	0.412	0.858
1763	CCEQ	1496.300	0.262	0.873
1764	CCS45	1496.367	0.328	0.958
1765	CCN45	1496.433	0.531	1.106
1782	CCEQ	1497.204	0.300	1.000
1784	CCN45	1497.274	0.418	0.871
1785	CCS45	1497.301	0.459	1.341

Table IV (Cont.)

June 1972 CO₂ Abundances

Scan No.	Orient.	JD (244-)	$\eta\omega_{\text{CO}_2}$ km-atm	$\eta\omega_{\text{CO}_2}$ (EQ)
1798	CCEQ	1498.169	0.398	1.327
1799	CCS45	1498.185	0.341	0.996
1800	CCN45	1498.203	0.578	1.204
1806	CCEQ	1500.263	0.297	0.990
1807	CCS45	1500.285	0.307	0.897
1808	CCN45	1500.310	0.431	0.898

Means of 7820Å and 8689Å CO₂ Bands

1718A	CCEQ	1492.250	--	0.859
1719A	CCS45	1492.280	--	1.117
1720A	CCN45	1492.340	--	1.129
1731A	CCEQ	1494.400	--	0.913
1732A	CCS45	1494.400	--	0.686
1733A	CCN45	1494.440	--	1.048
1748A	CCEQ	1495.140	--	1.008
1750A	CCS45	1495.200	--	1.020
1751A	CCN45	1495.200	--	0.899
1763A	CCEQ	1496.300	--	0.900
1764A	CCS45	1496.370	--	0.874
1765A	CCN45	1496.430	--	0.922
1782A	CCEQ	1497.200	--	1.195
1784A	CCN45	1497.270	--	0.979
1785A	CCS45	1497.300	--	1.131
1798A	CCEQ	1498.170	--	1.327
1799A	CCS45	1498.180	--	0.996
1800A	CCN45	1498.200	--	1.204
1806A	CCEQ	1500.260	--	1.070
1807A	CCS45	1500.280	--	0.949
1808A	CCN45	1500.310	--	0.869

Table V

Parameters Needed to Calculate CO₂ Equivalent Widths

Observational Period	CO ₂ Lines Included in Average	Base Width (Å) of Slit Function
September 1972	P8-16,22-32,36,38	0.771
August 1973	P8-16,22-32	0.771
October 1973	P8-16,22-32	0.692
December 1973	P8-16,22-32	0.665
January } February }	1974 P8-16,22-30	0.534

Observations of Venus Water Vapor
over the Disk of Venus:
The 1972-74 Data using
the H₂O Lines at 8197Å and 8176Å

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Tables 1

Proposed Running Head: Venus H₂O Variations

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ABSTRACT

The Venus water vapor line at 8197.71Å has been monitored at several positions on the disk of Venus and at phase angles between 21° and 162°. Variations in the abundance have been found with spatial location, phase angle and time. During the 1972-74 period, the total two-way absorption has varied from less than 1 to 77 microns of water vapor. The dependence on phase angle indicates 20 to 50 microns over the disk between 30° and 110° and small, but detectable amounts present during the rest of the observations. The spatial distribution with respect to the intensity equator is uniform with no location on the disk having systematically a higher or lower abundance. Comparisons made between the water vapor abundances and the CO₂ abundances determined from near simultaneous observations of CO₂ bands at the same positions on the disk of Venus show no correlation for the majority of the samples.

I. INTRODUCTION

As part of the continuing Venus and Mars observational program at McDonald Observatory, the several lines in the 8200Å water vapor band are monitored as frequently as possible to study variations in the observed abundance of Venus water vapor "above the clouds", and to follow the seasonal and spatial variations in the water vapor abundance in the Martian atmosphere. Both 2 Å/mm spectrographic plates and photoelectric scanner observations have been taken since completion of the 2.7m telescope in the spring of 1969. This paper will describe only the 196 photoelectric spectrum scans of Venus in the 8200Å water vapor band obtained since April 1972 and up to September 10, 1974. Part of these results have been presented before (Barker, 1974a) but the phase angle coverage has now been extended from 90° to 162° and additional observations made at 20°, 60°, and 77°.

II. INSTRUMENTATION AND REDUCTIONS

Photoelectric spectrum scans have been made using the rapid scanner at the coude focus of the 2.7m telescope which has an image scale of 2.3 arcsec per min, ideally suited for spatial resolution on planetary disks. We have used essentially the same system for the Mars and Venus

observations; a 79 groove per mm echelle grating in double pass which gives a very high dispersion of 8 mm/Å. With 200µm slits, a final resolution of about 30mÅ or 275,000 at 8200Å (FWHM) is attainable. The entire system is described in more detail by Tull (1972) and Wells (1972).

RCA GaAs (31034 and 31034A) photomultipliers have made these high resolution and photometrically accurate scans possible. The high quantum efficiency of these photomultipliers (10 to 20% at 8200Å coupled with the low dark count of 2 c/s at dry ice temperatures) make it possible to obtain high quality photoelectric scans of a single Venus line within 10 minutes. Scans can be made about 50 times faster now than when the echelle scanner was put into operation three years ago. Different slit widths or effective resolutions have been used to compensate for or take advantage of the quantum efficiency of the photomultiplier available at the time. In general, all the Venus scans have a resolution (FWHM) of 30mÅ.

Most strong water lines in the 8200Å band are contaminated to some degree by weak Fraunhofer lines primarily due to CN transitions, so care was taken in choosing the 8197Å line for Venus. All usable water lines (ie. free from major blends and having laboratory line strengths) have been observed on Mercury, as a source of variable Doppler shift, to look for "hidden" Fraunhofer lines.

Lines at 8141, 8193, and 8256Å are so seriously blended that they are not usable for future studies. Weak lines in the wings of 8176, 8189, and 8197Å have been measured and the H₂O lines can be used if the solar component of the Doppler shift does not place the "hidden" Fraunhofer lines at the Doppler shifted wavelengths of Mars and Venus water lines. The work presented in this paper uses primarily the line at 8197.7Å, with a few scans of the line at 8176.9Å.

An image rotator allowed the slit of the spectrograph to be oriented with respect to the intensity equator on Venus. On a few occasions a decker was used to shorten the slit to cover only part of the planet, but usually the slit length was just slightly larger than the planet's diameter to minimize the amount of sky background. The counting ratio between the planet-plus-sky and sky was monitored several times during each scan. Typically the sky contributed less than 5% of the total signal. With this ratio the appropriate amount of sky background was subtracted from each planet scan by using a sky or solar scan of the same wavelength regions obtained on the same day and at a similar airmass.

Each photoelectric scan is processed through several steps to remove effects of sky background, dark count level, and vignetting in the echelle system. The final plot of the

spectrum consists of data points representing the summation of the forward and reverse scans and a smooth curve through these data points which has been drawn by the computer as a result of a Fast Fourier Transform smoothing and interpolating operation on the data. All equivalent widths are measured by an area planimeter with respect to such a smoothed curve and the local continuum. The local continuum curve in the telluric water line has been transferred from a solar scan of similar water content taken on the same day.

Attempts have been made to produce a synthetic solar spectrum scan to calculate a ratio spectrum with the planetary scan leaving only the planetary component of the water line. Both methods have the same major source of error (namely the placement of the continuum level), and we feel that we are adding an additional source of error by trying to produce a solar scan having identical water content and instrumental resolution.

Because the amounts of water vapor in the Venus spectrum tend to be small ($\leq 10\mu\text{m}$) when the Doppler shift is small, we found it necessary to use the ratio spectrum method to measure such small amounts. Usually a solar scan of the telluric line was made at the identical water content, but if this was not possible or the range in airmass of the Venus scans was too great, we synthesized a telluric line by matching it to the observed solar scan. Then by changing the abundance in the synthetic profile, a matching

solar scan was obtained for each Venus scan. This procedure was followed for the 1974 scans taken with $i > 130^\circ$ and $i \sim 22^\circ$. An original Venus spectrum and its ratio spectrum with a synthetic solar scan appears in Figure 1.

III. OBSERVATIONS

The 107-inch echelle-coude scanner has proven to be well suited for spatial studies of Venus water vapor, mostly because of its speed, a prime requirement for spatial studies requiring good seeing over a long period of time. With a resolution of $30\text{m}\text{\AA}$ (FWHM) which is better than the resolution of a $2\text{\AA}/\text{mm}$ spectrographic plate, we can obtain a water line scan in 10 minutes, compared to a plate exposure of one hour. This means we can observe at many locations on the disk of Venus during a few hours of good seeing.

The physical data for the 196 Venus scanner observations of the $8197.7\text{\AA}$ and $8176.9\text{\AA}$ lines appear in Table I. The phase angle coverage is good between 20° and 112° with observations extending to 162° . The data presented in Table I are far greater phase angle and spatial coverage than any of the previous measurements of Venus water vapor. Traub and Arleton (1973a, b) have made single observations at phase angles of 50° and 156° . Schorn, et al. (1969) presented observations over phase angles of 52° and 92° . It is difficult to observe near phase angles of 0° and 180° because

of the small Doppler shifts involved. The scanner resolution and terrestrial water vapor limit the useful Doppler shift range to greater than $\pm 0.10\text{\AA}$ which corresponds to approximate phase angle limits of $20^\circ < i < 160^\circ$.

Total abundances ($\eta\omega$) for a two-way absorption through the Venus atmosphere were calculated on assumptions of an effective pressure of 136mb and a temperature of 250°K . The H_2O line strengths (Farmer, 1971) at 250°K and the tables of Jansson and Korb (1968) with $a = 1.0$ were used to calculate total abundances from the observed equivalent widths. The internal error involved in a scan is around $\pm 1.5\mu\text{m}$ of precipitable H_2O . A complete tabulation of the Venus H_2O abundances has been made in Table I. The quality of each scan has been indicated and is a measure of the accuracy of the continuum placement, position of the Venus H_2O feature with respect to the expected Doppler position and random noise present in the photoelectric data.

Putting the amount of ≤ 1 to $77\mu\text{m}$ of water vapor in perspective with previous measurements, they fall between the total disk values of Fink, et al. (1972) who found $1.6\mu\text{m}$ for the water bands at 1.4 , 1.9 , and 2.7μ , ($i = 86^\circ$, 105°), and those found by Schorn, et al. (1969) and Owen (1968) of ≤ 64 to $120\mu\text{m}$ using several lines in the $8200\text{\AA}$ band. Gull, et al. (1974) found $3 \pm 20\mu\text{m}$ using an airborne echelle spectrograph to observe 20 strong lines in the $8200\text{\AA}$ H_2O

band at $i = 87^\circ$. A very important difference in the observational techniques is that Fink, Gull, and Traub and Carleton are measuring a planet wide average of the H_2O content whereas Schorn, Owen and the present study are measuring the content over a specific small portion of the disk.

Variability of amount of water vapor in the total pathlength with position on the disk is illustrated in Figures 2 and 3. Figure 2 shows the red wing of the $8197\text{\AA}$ water line for two different spectrograph slit positions, S1/4 and N3/4. The wavelength range is about $1\text{\AA}$. The slit in most cases was placed parallel to the intensity equator and the N-S notation is for convenience only to indicate a relative fraction North or South on the visible disk from the intensity equator. It does not refer to the actual N-S direction on Venus. An upper limit of $5\mu\text{m}$ of the S1/4 position contrasts with the easily detectable amount of $30\mu\text{m}$ at the N3/4 position. The two scans shown in Figure 3 again graphically show that we can find different amounts of water vapor at different locations on the disk. The $56\mu\text{m}$ in the equator scan is one of the largest amounts detected during the August 1972 through September 1974 period. This line would have barely been detectable on $2\text{\AA}/\text{mm}$ spectrographic plates. Comparable amounts have been seen on many spectrographic plates taken at McDonald since 1967, but the spectrographic plates lacked the spatial resolution and photometric accuracy needed to

detect smaller amounts.

To increase the number of positions we could measure, on several occasions the length of the scan range was decreased just to include the Doppler shifted Venus H₂O line. At least one scan per observing period was obtained of the entire profile for continuum placement and wavelength measurement. An example of this type of shorter scan is shown in Figure 4.

IV. DISCUSSION

A summary of spatial distribution of the data in Table I is presented in Figure 5 in histogram form with the number of samples at that location in parentheses above the level of the mean value. The various slit positions are explained in the caption and in Table I. There does not seem to be any preferential location for high or low abundances. The error of a single observation is $\pm 3\mu\text{m}$, but the standard error of the mean value is larger, even for the positions with greater than 20 samples. This is consistent with the samples having a large real scatter in indance.

Variation of the equivalent width of a line as a function of phase angle can be used as a parameter in models to explain the vertical structure of the Venus atmosphere (Hunt, 1972a, b; Margolis and Hunt, 1973; Regas, et al., 1973a, b, 1974; and Whitehill and Hansen, 1973). In Figure 6 the 1972-74 observations of total water vapor abundance on

Venus are plotted as a function of phase angle and/or time. Several points at one phase angle indicate abundance variations for various slit positions on that day. A typical internal error bar is $\pm 3\mu\text{m}$; these have been left off the figure for clarity. Some scans exhibited no Venus water line at all and are indicated by vertical arrows representing an upper limit to the abundance for that scan.

A general correlation between phase angle and water vapor abundance is present in Figure 6; but, the large scatter on a single day or at any one phase angle suggests the conclusion that we are observing a random event. A correlation has been looked for between H_2O and CO_2 abundances and none has been detected (Barker, 1974). However, there is a possibility of preferential appearance of the larger abundances at intermediate phase angles 35° to 90° . Observations of lower abundances at phase angles greater than 140° and less than 30° are consistent with the two observations of Traub and Carleton (1974a, b) in which they report no line greater than $0.1\text{m}\text{\AA}$ or a total abundance of $1\mu\text{m}$ at $i = 156^\circ$ and a detectable line of $0.5\text{m}\text{\AA}$ or a total abundance of $5\mu\text{m}$ at $i = 50^\circ$. As indicated earlier, the Doppler shifts are small in these phase angle ranges ($i < 20^\circ$, $i > 150^\circ$) and may lead to large uncertainties in the measured equivalent widths of non-terrestrial water lines which are masked by strong telluric components only $0.1\text{\AA}$ away. Only observations with very high resolution ($>250,000$) and dry terrestrial conditions can be used

when the Doppler shifts are so small. The attempts made at McDonald to observe at phase angles greater than 150° in January of 1974 during our dry season were highly successful due to the large number of days when the vertical H_2O content above the observatory was 1mm or less of precipitable water vapor. Since we had a very large crescent (>40 arcsec), we hoped to see any variations in the spatial distribution along the crescent similar to CO_2 abundance variations of a factor of two or three noted during the 1972 inferior conjunction (Barker and Schorn, 1973) and the 1974 inferior conjunction (Barker, 1974b and Barker and Perry, 1974). The amounts of water vapor at 1 and $10\mu m$ observed at large phase angles ($i > 135^\circ$) were marginal. But, five of the scans were of very high quality definitely indicating the presence of water vapor at these phase angles. An example of one of these scans is shown in Figure 1.

Mixing ratios of 0.5×10^{-6} to 4×10^{-5} correspond to the range in the observed H_2O abundances presented in this paper assuming a reflecting layer model and an average CO_2 abundance of 2 km-atm above the clouds which in itself varies (Fink, et al., 1974; Barker, 1974b; Barker and Perry, 1974). These results appear to also fall in the range between previous observational results of Fink, et al. (1972) and those of Schorn, et al. (1969) and Owen (1968). As Schorn et al. (1969) stated we are in the favorable position of agreeing with everyone some of the

time. The integrated disk measurement of Fink, et al. (1972) and Gull, et al. (1974) are lower because of the averaging effect of the "wet" spots on the planet. The data presented in this paper show that one does indeed observe the "wet" locations occasionally.

The cause behind this patchiness of H_2O content could very likely be the distribution of H_2SO_4 in the upper atmosphere of Venus. Since H_2SO_4 is such a powerful hygroscopic material, a small variation in the concentration from 80 to 90% would alter the water vapor abundance by a factor of about 100 (Fink, et al., 1974; Regas, et al., 1974; Young, 1973). The question of whether the clouds act as pure scatterers or also act as absorbers (Regas, et al., 1974) may be answered by a detailed look at the line profile of the observed water vapor lines. The Venus H_2O lines are much broader than the Martian H_2O lines observed at the same resolution. Whether this increase in line width is only due to the increase in the effective pressure is presently under study.

It will be possible to intercompare the CO_2 and H_2O abundances for about 32 days during September 1972 and July, August, October, December of 1973 and January, February of 1974. The existence of a matching CO_2 abundance determination is noted in Table I by a + in the CO_2 column. This comparison will be the subject of an additional paper (Barker, 1974d), but any correlation (positive or negative) is nonexistent,

although on an individual day a positive correlation exists. Although the CO_2 line strengths showed variations of a factor of two or more during the 1974 inferior conjunction, the water vapor variations of 1 to $10\mu\text{m}$ were not correlated. Consequently, one has to conclude the CO_2 and H_2O levels of line formation do not vary in phase in the upper atmosphere.

The Venus water vapor observations during 1972-74 show quite conclusively a day-to-day abundance variation and also a significant abundance variation with position on the disk of Venus on any single day. Consequently, the level or altitude of line formation must change, consistent with vertical and/or horizontal movement of the altitude of "tops" of the lower cloud deck. Only at moderate phase angles, 40° to 90° , can we look into the Venus clouds deep enough to detect $50\mu\text{m}$ or more of precipitable water vapor. At other phase angles we are observing residual amounts in the upper atmosphere. It is hoped that in presenting such a bulk of Venus H_2O data as in Table I and also for the CO_2 abundances in Barker and Perry (1974) and Barker (1974d) we are providing the data to analyze the Venus atmosphere with specific parameters at individual locations on the disk of Venus and not have to rely on "interpolated" H_2O equivalent widths as Regas, et al. (1973, 74) have done.

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LIST OF FIGURE CAPTIONS

Fig. 1. Comparison of local continuum and ratio spectrum of same line. The ratio spectrum (b) is a ratio between the Venus scan (a) and a synthetic telluric water vapor line with an effective pressure of 700mb and an abundance of 1.3mm of precipitable water vapor. The position of 8197Å water vapor line on Venus is indicated by the ♀ symbol. The slit position is shown in the small insert. The channel separation is 11.8mÅ. The maximum intensity in part (a) refers to a total of 68,000 counts.

Fig. 2. The position of 8197Å water vapor line on Venus is indicated by the ♀ symbol. The slit position is shown in the small insert. The channel separation is 11.8mÅ. The maximum intensity in both scans refers to a total of 23,700 counts.

Fig. 3. The position of 8197Å water vapor line on Venus is indicated by the ♀ symbol. The slit position is shown in the small insert. The channel separation is 11.8mÅ. The maximum intensity refers to a total of 52,400 counts for the EQ scan and 21,000 counts for the N/2 scan.

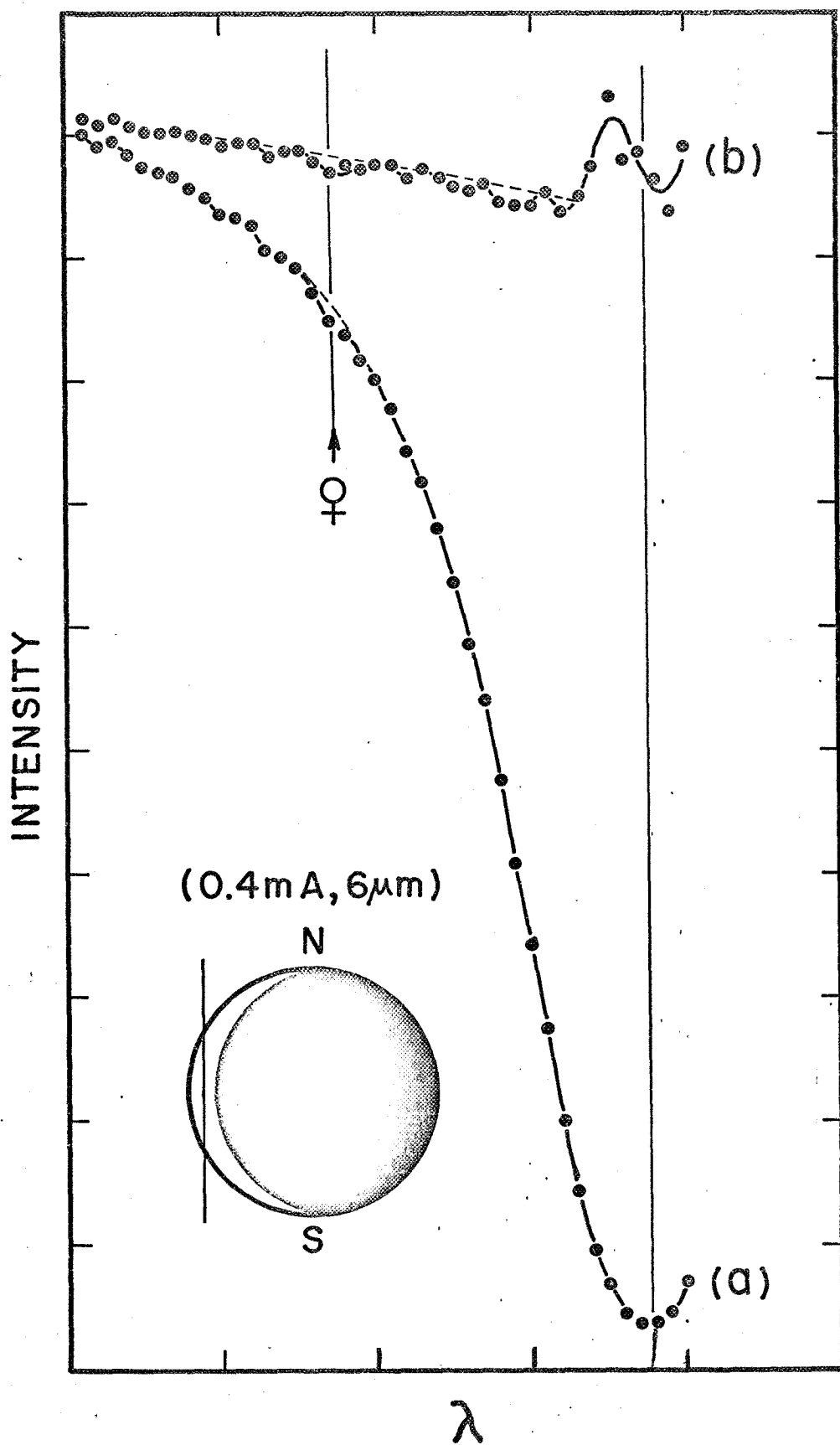
Fig. 4. Example of shortened scan range to decrease observing time. The position of 8197Å water vapor

line on Venus is indicated by the φ symbol. The slit position is shown in the small insert. The channel separation is 11.8mÅ. The maximum intensity refers to a total of 16,700 counts for the EQ scan and 33,600 counts for the N/3 scan.

Fig. 5. Spatial distribution of water vapor determinations over the disk of Venus. Slit positions: Parallel to intensity equator at various fractions of disk diameter toward poles; N3/4, N2/3, N/2, N/3, N/4, EQ, S/4, S/3, S/2, S2/3, S3/4. Perpendicular to intensity equator or pole to pole at various fractions of disk diameter; T designates terminator, CM--central meridian, CD--center of the disk, L--limb. Number of samples is in parentheses and standard error of the mean is the vertical error bar.

Fig. 6. Venus water vapor determinations at different phase angles, i . Quality: 1 - $\bullet$, ± 1 to $4\mu\text{m}$; 2 - $+$, ± 4 to $6\mu\text{m}$; 3 - $\circ$, ± 6 to $10\mu\text{m}$.

VENUS H_2O 8197 Å
1/03/74 DIA. = 52.8" $\iota = 138^\circ.6$



VENUS H₂O 8197A
8/24/72 DIA. = 24.4''

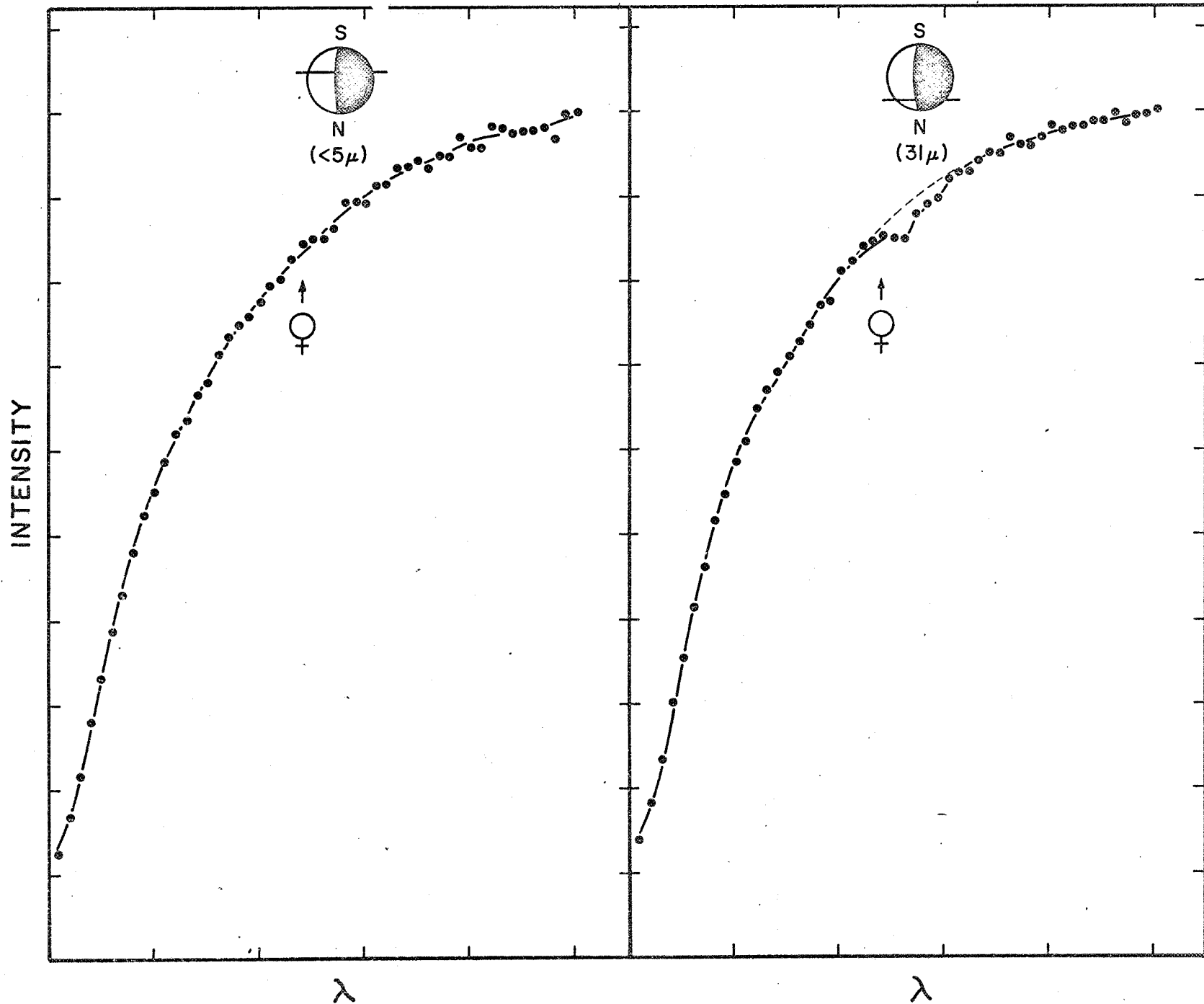
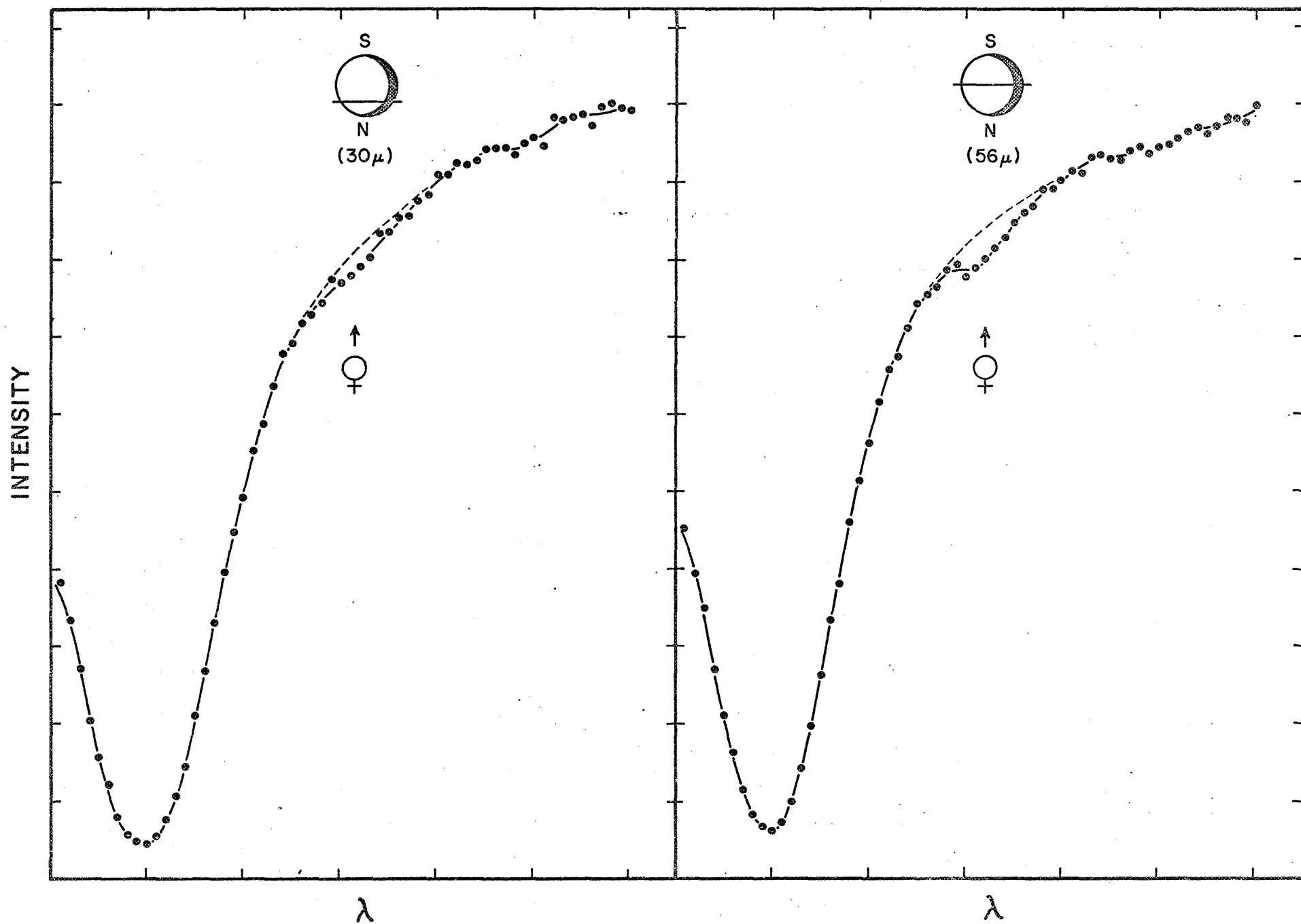
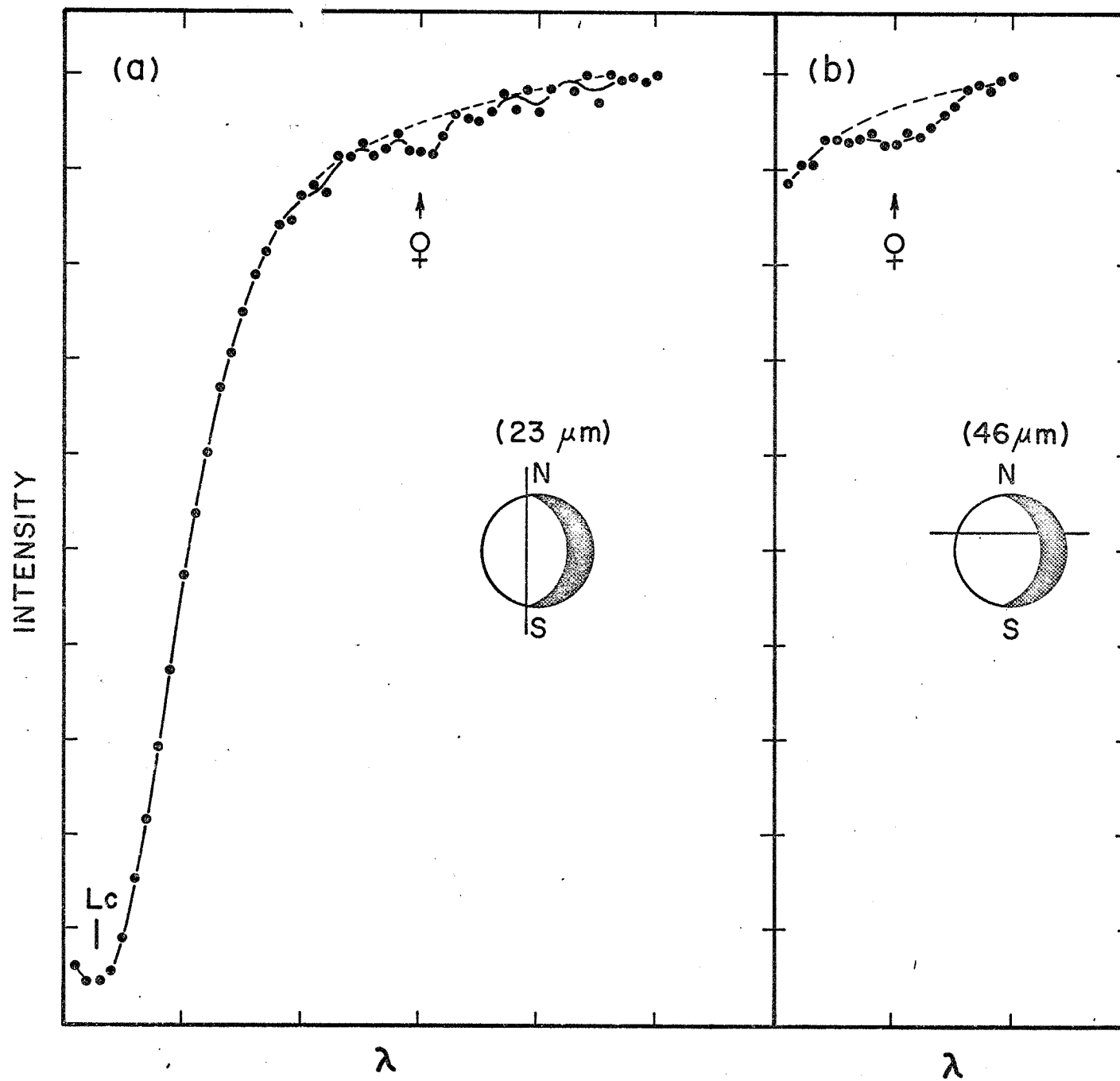


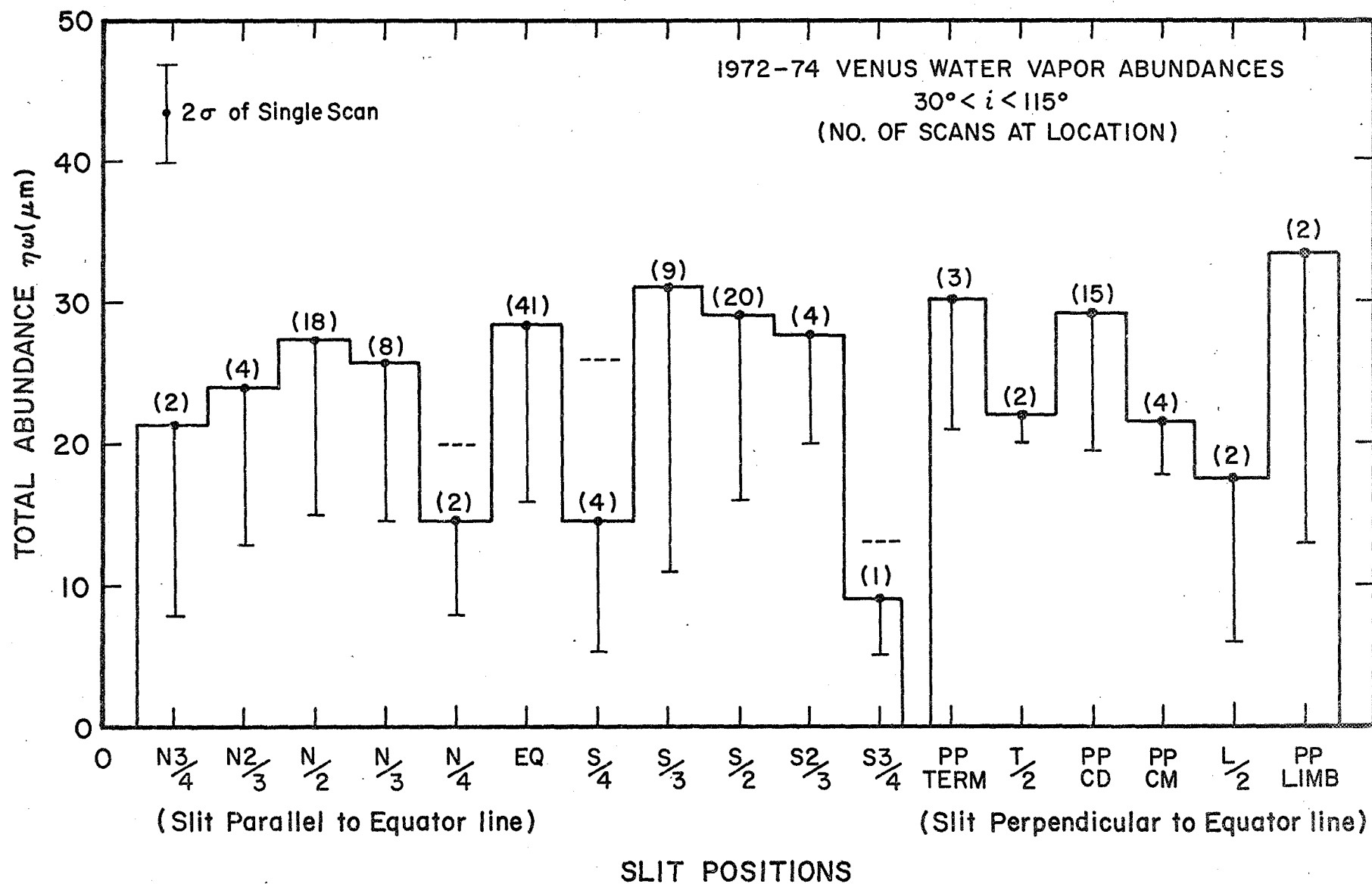
FIGURE 1

VENUS H₂O 8197A
11/25/72 DIA. = 12.7^u



VENUS H₂O 8197 Å
6/07/74 DIA. = 15.1''





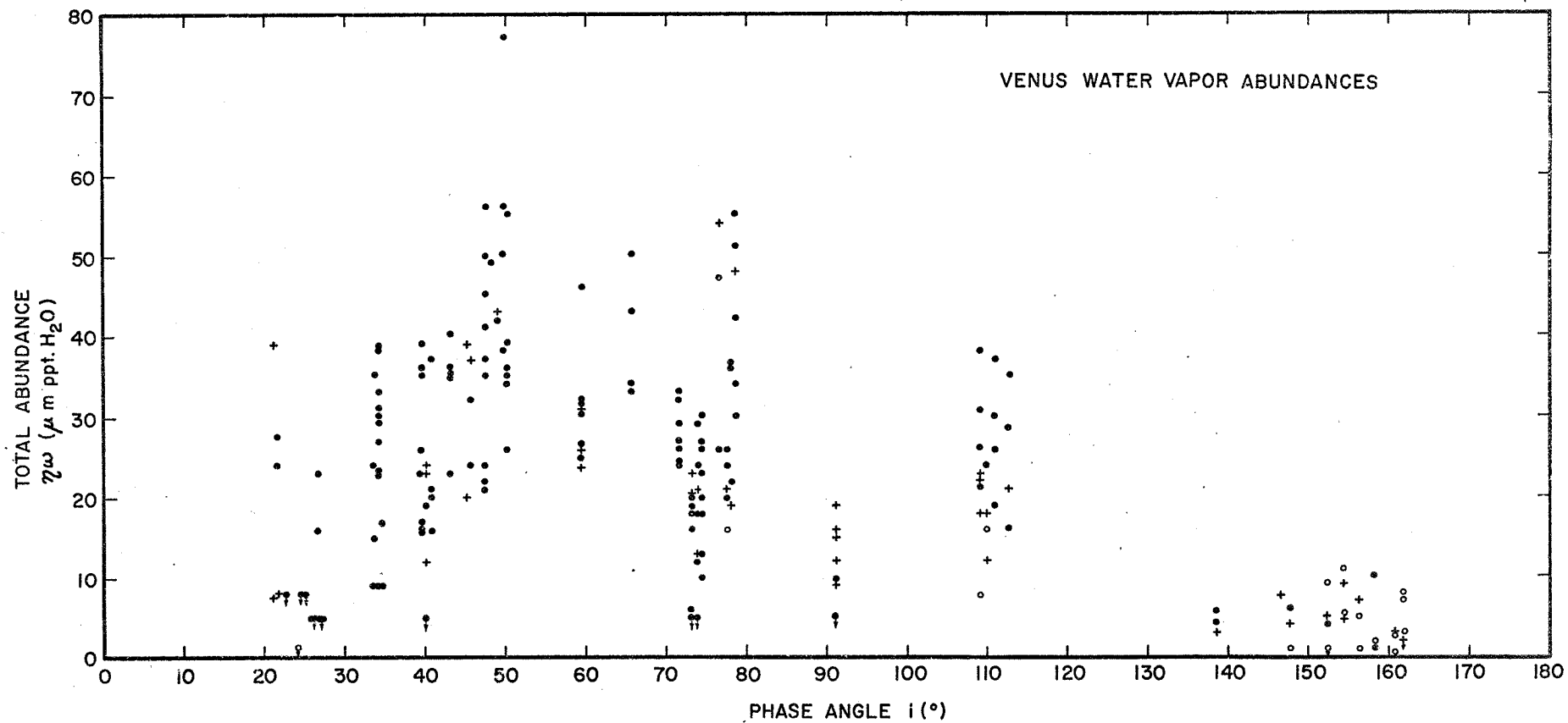


Table I

Venus 1972-1974 H₂O Observations

Physical Parameters				CO ₂ Obs.	H ₂ O Abundances				
Date	$\Delta\lambda$ (Å)	i (°)	Diameter (arcsec)		Scan No.	Orient. ¹	W _o (mÅ)	$\eta\omega$ (μm)	Quality ²
08/25/72	+.369	91.0	24.4	+	1987	EQ	1.01	15	2
					1988	EQ	0.80	12	2
					1989	S/2	0.59	9	2
					1990	N/2	1.07	16	2
					1991	N/4	1.25	19	2
					1992	S/4	--	<5	1
					1993	S3/4	0.65	9	1
					1994	N3/4	2.07	31	1
					1995				
09/23/72	+.350	74.3	18.4	+	2258	EQ	1.78	27	1
					2259	S/2	2.01	30	1
					2260	N/2	1.54	23	1
					2261	N/4	0.69	10	1
					2262	S/4	0.88	13	1
					2263	EQ	1.28	20	1
					2264	EQ	1.19	18	1
					2265	EQ	1.67	26	1
09/24/72	+.350	73.8	18.2		2268	EQ	1.63	24	1
					2269	N3/4	0.79	12	1
					2270	N/2	1.23	18	1
					2271	S/2	1.36	21	2
					2272	S/2	--	<5	1
					2273	S/4	0.89	13	2
					2274	S/4	1.94	29	1
09/26/72	+.347	73.3	17.9	+	2320	EQ	1.07	16	1
					2321	EQ L/3	1.27	20	1
					2322	EQ C/3	1.50	23	2
					2323	EQ T/3	1.34	20	2
					2324	N/3	0.45	6	1
					2325	S/3	--	<5	1
					2326	PP C/3	0.94	13	1
					2327	PP L/3	0.96	14	1

Table I (Cont.)

Venus 1972-1974 H₂O Observations

Physical Parameters				CO ₂ Obs.	H ₂ O Abundances				
Date	$\Delta\lambda$ (Å)	i (°)	Diameter (arcsec)		Scan No.	Orient. ¹	W _o (mÅ)	$\eta\omega$ (μm)	Quality ²
09/29/72	+.344	71.4	17.5	+	2534	EQ	1.90	29	1
					2535	N2/3	1.70	26	1
					2536	N/3	2.13	32	1
					2537	S/3	2.18	33	1
					2538	S2/3	1.60	24	1
					2539	PP T/3	1.60	24	1
					2540	PP L/3	1.76	27	1
11/25/72	+.262	47.2	12.7		2782	EQ	3.63	56	1
					2783	S/2	3.21	49	1
					2784	N/2	2.45	37	1
					2785				
11/30/72	+.253	45.2	12.5		2815	EQ	1.45	22	1
					2816	EQ	2.29	35	1
					2817	S/2	1.56	24	1
					2818	N/2	2.67	41	1
					2824	N/2	1.40	21	1
12/01/72	+.251	42.9	12.4		2849	EQ	2.33	35	1
					2850	EQ	2.33	35	1
					2851	S/2	2.59	40	1
					2852	N/2	2.38	36	1
					2853	PP CM	1.54	23	1
12/12/72	+.231	40.4	11.9		2908	EQ	1.31	20	1
					2909	EQ	1.41	21	1
					2913	PP CM	1.09	16	1
					2914	EQ	2.48	37	1
12/13/72	+.229	40.0	11.8		2943	EQ	0.87	12	2
					2944	PP CM	1.61	24	2
					2945	EQ	1.22	19	1
					2946	S/2	1.57	23	2
					2947	N/2	--	<5	1
12/14/72	+.227	39.6	11.8		2971	EQ	1.18	17	1
					2972	S/2	1.09	16	1
					2973	N/2	1.14	17	1
12/16/72	+.225	38.9	11.7		3012	EQ	2.38	36	1
					3013	N/2	2.28	35	1
					3014	S/2	1.69	26	1
					3015	PP CM	1.47	23	1

Table I (Cont.)

Venus 1972-1974 H₂O Observations

Physical Parameters				CO ₂ Obs.	H ₂ O Abundances				Quality ²
Date	$\Delta\lambda$ (Å)	i (°)	Diameter (arcsec)		Scan No.	Orient. ¹	W _O (mÅ)	$\eta\omega$ (μm)	
06/05/73	-.139	21.2	10.2		3653	EQ	--	<8	1
					3654	N/2	--	<8	1
					3655	S/2	--	<8	1
					3656	PP CD	--	<8	1
06/14/73	-.164	24.8	10.4		3740	EQ	--	<8	1
					3742	EQ	--	<8	1
06/16/73	-.169	25.6	10.4		3789	EQ	--	<5	1
					3790	N3/4	--	<5	1
					3791	N/2	--	<5	1
					3792	N/4	--	<5	1
					3793	S/4	--	~5	1
					3794	S/2	--	<5	1
					3795	S3/4	--	<5	1
06/17/73	-.171	26.0	10.4		3818	EQ	--	<5	1
					3819	S/2	--	~5	1
					3820	N/2	--	~5	1
					3822	PP CD	--	<5	1
					3823	EQ	1.51	23	1
					3824	S/2	1.01	16	1
					3825	N/2	--	<5	1
07/06/73	-.219	33.7	11.0	+	3859	EQ	2.27	35	1
					3860	S/2	0.97	15	1
					3861	N/2	0.58	9	1
					3862	PP CD	1.58	24	1
07/07/73	-.221	34.1	11.0		3919*	EQ	2.53	38	1
					3920*	N/2	2.06	30	1
					3921*	S/2	2.53	38	1
					3922*	PP CD	2.25	33	1
					3926	PP CD	1.77	27	1
					3927	EQ	2.04	31	1
					3928	S/2	1.51	23	1
					3929	N/2	1.88	29	1
					3930	PP T/2	1.53	23	1
					3931	PP L/2	0.57	9	1
07/08/73	-.223	34.5	11.0		3971	EQ	1.14	17	1
					3974	EQ	0.56	9	1

Table I (Cont.)

Venus 1972-1974 H₂O Observations

Physical Parameters				CO ₂ Obs.	H ₂ O Abundances				
Date	$\Delta\lambda$ (Å)	i (°)	Diameter (arcsec)		Scan No.	Orient. ¹	W_o (mÅ)	$\eta\omega$ (μ m)	Quality ²
08/03/73	-.276	45.1	11.3		4020	EQ	1.36	20	2
					4021	S/2	2.63	39	2
08/04/73	-.278	45.5	11.4		4078	N/2	1.60	24	1
					4079	S/2	2.18	32	1
					4081	EQ	2.85	42	2
08/10/73	-.288	47.9	11.7	+	4327	EQ	3.26	49	1
08/12/73	-.291	48.7	11.8	+	4391	EQ	2.72	42	1
					4392	S/2	2.79	43	2
08/14/73	-.294	49.5	12.7	+	4446	EQ	3.61	56	1
				+	4447	N/3	2.45	38	1
				+	4448	S/3	4.87	77	1
					4449	PP CD	3.22	50	1
08/15/73	-.296	49.9	12.8	+	4475	EQ	3.49	55	1
				+	4476	N/3	2.18	34	1
				+	4477	S/3	1.66	26	1
				+	4478	S2/3	2.51	39	1
				+	4479	N2/3	2.30	35	1
					4480	PP CD	2.33	36	1
08/22/73	-.306	65.6	13.3	+	4599	EQ	2.27	33	1
					4600	N/2	2.34	34	1
					4602	S/2	2.91	43	1
				+	4603	PP CD	3.37	50	1
10/17/73	-.354	76.5	19.3	+	4713	EQ	1.66	26	1
				+	4714	S/2	3.44	54	2
				+	4715	N/2	3.02	47	1
10/19/73	-.354	77.5	19.7	+	4732	EQ	1.36	21	2
				+	4734	N/2	1.58	24	1
				+	4735	S/2	1.04	16	3
				+	4736	PP CD	1.71	26	1
				+	4737	TERM	1.28	20	1
10/20/73	-.355	77.9	19.8	+	4767	PP CD	2.35	36	1
				+	4768	TERM	2.34	36	1
					4769	LIMB	1.23	19	2
				+	4771	EQ	1.45	22	1

Table I (Cont.)

Venus 1972-1974 H₂O Observations

Physical Parameters				CO ₂ Obs.	Scan No.	H ₂ O Abundances			
Date	$\Delta\lambda$ (Å)	i (°)	Diameter (arcsec)			Orient. ¹	W _O (mÅ)	$\eta\omega$ (μm)	Quality ²
10/21/73	-.355	78.4	20.0	+	4802	PP CD	1.92	30	1
				+	4803	TERM	3.51	55	1
				+	4804	LIMB	3.06	48	2
				+	4805	EQ	2.72	42	1
				+	4806	S/2	2.24	34	1
				+	4807	N/2	3.28	51	1
12/09/73	-.336	109.0	37.1	+	4925	EQ	2.00	31	1
				+	4926	N2/3	0.50	8	3
				+	4927	N/3	1.48	23	2
				+	4928	S/3	2.47	38	1
				+	4929	S2/3	1.38	21	1
				+	4930	PP CD	1.16	18	2
				+	4931	PP L/2	1.71	26	1
				+	4932	PP T/2	1.36	21	2
12/10/73	-.334	109.9	37.7	+	4955	PP CD	0.78	12	2
				+	4956	EQ	1.15	18	2
				+	4957	S/3	1.57	24	1
				+	4958	N/3	1.06	16	2
12/11/73	-.332	110.8	38.8	+	4982	PP CD	1.92	30	1
				+	4983	EQ	1.71	26	1
				+	4984	N/3	2.42	37	1
				+	4985	S/3	1.23	19	1
12/13/73	-.327	112.6	39.4	+	5044	EQ	2.29	35	1
				+	5045	N/3	1.34	21	2
				+	5046	S/3	1.86	29	1
				+	5047	PP CD	1.06	16	1
01/03/74	-.227	138.6	52.8		5105	CC EQ	0.38	6	1
					5106	CC S22	0.28	4	1
					5107	CC N22	0.19	3	2
01/07/74	-.192	146.4	58.6		5114	CC EQ	0.50	8	2
01/14/74	-.114	158.7	60.4	+	5129	CC S22	≤ 0.09	1	1
				+	5132	CC N45	0.16	2	3
01/15/74	-.103	160.6	60.9	+	5152	CC EQ	< 0.04	0.6	3
				+	5153	CC S22	0.21	3	2
				+	5154	CC N22	0.19	3	3

Table I (Cont.)

Venus 1972-1974 H₂O Observations

Physical Parameters				CO ₂ Obs.	H ₂ O Abundances				
Date	$\Delta\lambda$ (Å)	i (°)	Diameter (arcsec)		Scan No.	Orient. ¹	W_o (mÅ)	$\eta\omega$ (μ m)	Quality ²
01/30/74	+.103	161.7	60.7	+	5332	CC EQ	0.45	7	3
					5333	CC EQ	<0.08	<1	2
					5334	CC EQ	0.50	8	3
					5335	CC N22	0.17	3	3
02/01/74	+.126	158.0	59.7	+	5381	CC N22	0.66	10	1
02/02/74	+.138	156.2	59.1	+	5402	CC EQ	0.09	1	3
					5403	CC S22	0.32	5	3
					5405	CC N22	0.48	7	2
02/03/74	+.150	154.3	58.5	+	5435	CC EQ	0.70	11	3
					5437	CC S22	0.57	9	2
					5438	CC N22	0.32	5	2
					5439	CC N22	0.32	5	3
02/04/74	+.162	152.3	57.9	+	5463	CC EQ	0.24	4	1
					5464	CC S22	<0.08	<1	3
					5465	CC N22	0.56	9	3
					5466	EQ	0.31	5	2
02/07/74	+.193	147.2	55.6	+	5529	CC EQ	<0.08	1	3
					5530	CC N22	0.37	6	1
					5531	CC S22	0.24	4	2
06/07/74	+.329	59.3	15.1		5945	PP CD	1.52	23	2
					5946	PP L/3	2.01	31	1
					5947	PP CD	1.95	30	1
					5948	PP T/3	2.05	32	1
					5949	N2/3	1.75	27	1
					5950	N/3	2.95	46	1
					5951	EQ	1.63	25	1
					5952	S/3	1.99	31	2
					5953	S2/3	1.67	26	2
09/01/74	+.149	24.6	10.4		6261F	EQ	<0.08	1	3
09/09/74	+.129	21.4	10.3		6410F	EQ	1.80	28	1
					6411F	PP CD	1.56	24	1
					6412F	EQ	0.49	8	2
09/10/74	+.127	21.0	10.2		6436	PP CD	2.52	39	2
					6437	EQ	0.49	8	2

Table I (Cont.)

Venus 1972-1974 H₂O Observations

¹Slit Orientations: Parallel to intensity equator at various fractions of disk diameter toward poles; N3/4, N2/3, N/2, N/3, N/4, EQ, S/4, S/3, S2/3, S3/4. Perpendicular to intensity equator or pole to pole at various fractions of disk diameter; T designates terminator, CM--central meridian, CD--center of disk, L--limb; PP T/3, PP T/2, PP CM, PP C/3, PP CD, PP L/2, PP L/3. Inferior conjunction observations were made with the slit as a cord along the crescent. Positions denoted by latitude of tangent point along the crescent; CC N45, CC N22, CC EQ, CC S22, CC S45.

²Quality: 1 = ± 1 to 4 μ m ppt. H₂O; 2 = ± 4 to 6 μ m ppt. H₂O; 3 = ± 6 to 10 μ m ppt. H₂O.

*Observations of 8176.9Å H₂O line.